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MAGNETIC ALLOYS OF IRON, NICKEL, AND COBALT.*

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IF the three ferromagnetic metals, iron, nickel and cobalt, are melted together in various proportions, all of the resultant alloys are magnetic when the materials used are reasonably pure. The magnetic properties of the alloys, however, vary greatly with composition and heat treatment. Some alloys have been found to be nearly non-magnetic; others have higher permeability than any hitherto known magnetic material and may be magnetically saturated in the earth's field. Still others are superior at high field strengths or excel in constancy of permeability at low fields.

In the Bell Telephone Laboratories we have been especially interested in these alloys and have made a fairly complete survey of the magnetic properties of the whole field of compositions of these metals. In this address I wish to tell you how our interest in these alloys was aroused, what our procedure was in carrying out an investigation, and what some of the principal results were. I shall also refer to some of the particular applications which we have made as a result of our discoveries.

I first became interested in these alloys in 1913. At that time I was looking for a magnetic material which would be more suitable for certain uses in the electrical communication

* Presented at a meeting held Thursday, November 8, 1928.

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field than the iron then used. Of the large number of alloys investigated, several contained principally iron and nickel. One of these was particularly interesting. The composition of this alloy was approximately 70 per cent. nickel and 30 per cent. iron; it was a commercial alloy used as a special resistance material. In the hard worked condition in which it was supplied, its magnetic properties were not even as good as iron in a similar magnetic condition, but when heat-treated it was superior to the iron at low field strengths, the region in which I was especially interested.

This alloy differed from iron in another important characteristic. Experience with iron had shown that the best magnetic quality was obtained when the material was heated to a high temperature, and then cooled slowly to room temperature. It was considered particularly important to cool slowly in order to give the iron time to pass through its transformations and to allow it to build up a large grain structure. When the nickel-iron alloy was heat-treated in this manner, it was found to have lower permeability than it had when cooled fairly rapidly.

The discovery that rapid cooling was required for this alloy to give the best magnetic quality was one of the major contributions from our early work. It showed us that one of the important factors in developing the magnetic properties of new alloys was the determination of the rate of cooling for the best magnetic quality for each alloy.

Another difference between this alloy and iron relates to the energy loss caused by the hysteresis at low flux densities. In this range iron has lower hysteresis loss when it is in a mechanically hard condition than when it is well annealed. As the flux density increases, however, the hysteresis loss of the hard material increases more rapidly than does that of the annealed and at medium and high flux density, the mechanically hard iron is much inferior. Tests on the nickel-iron alloy show that both for high and low flux densities the hysteresis loss was a great deal higher for the mechanically hard material than for the one heat-treated to give the best magnetic quality.

The discovery of the unusual magnetic properties of this 70–30 per cent. nickel-iron alloy gave us the lead that we were

looking for, and started our investigation of the magnetic properties of the whole series of nickel-iron alloys. We found, as we had reason to expect, that the 70–30 per cent. alloy was one of a large group of alloys in the same series which had similar magnetic properties. In fact substantially all of the alloys containing more than 30 per cent. nickel had similar characteristics except that some of them were not as sensitive to heat-treatment as the first alloy we had tested.

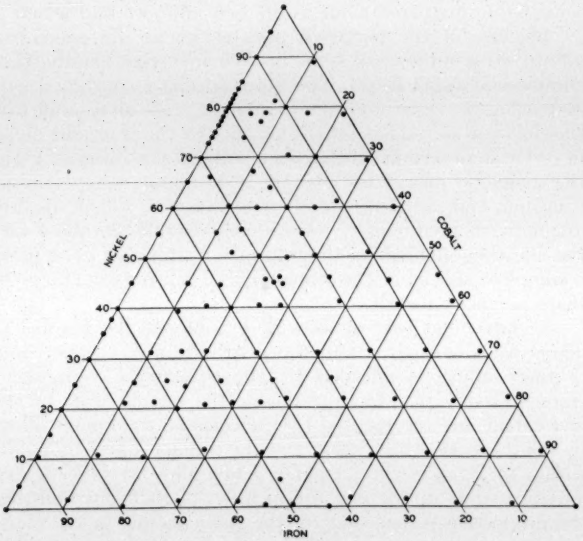
Because of the technical possibilities of the nickel-iron alloys, we spent several years in their investigation and their commercial application. We were especially concerned with increasing the resistivity of a number of these alloys and with this in view we added other elements to the iron and nickel in order to determine their effect both on the resistivity and the magnetic properties. Copper, chromium, molybdenum, tungsten, and tantalum are a few of those we added; also the magnetic element cobalt. The striking results obtained with the addition of cobalt to the iron-nickel alloys led us to make a complete survey of the whole field of alloys containing the three magnetic metals.

A convenient way of showing graphically the number of alloys we investigated and the distribution of compositions of these alloys is afforded by the equilateral composition triangle in Fig. 1. In this triangle the metals, iron, nickel, and cobalt, are represented by the corners; the binary alloys by points on the three sides, and the ternary alloys by points within the area of the triangle. Each alloy we investigated is indicated by a dot and the location of each dot indicates the proportion in per cent. of the three metals in the alloy. A glance at the diagram will give you an appreciation of the completeness with which the field was covered.

In preparing these alloys we used the best commercial materials available. These contained small amounts of impurities some of which affect unfavorably the magnetic properties. It was considered beyond the scope of this investigation, in which such a large number of alloys were required, to attempt to remove these impurities completely or even partially. Moreover we were especially interested in alloys which could be reproduced on a commercial scale, without too great cost due to refinements of raw materials or to methods of preparing the alloys.

Throughout the investigation we have followed a standard procedure for preparing our samples. We have also followed a standard procedure for heat-treating and in magnetic measurements. The result is that we have accumulated a large mass of data over a number of years all of which may be significantly compared.

FIG. 1.

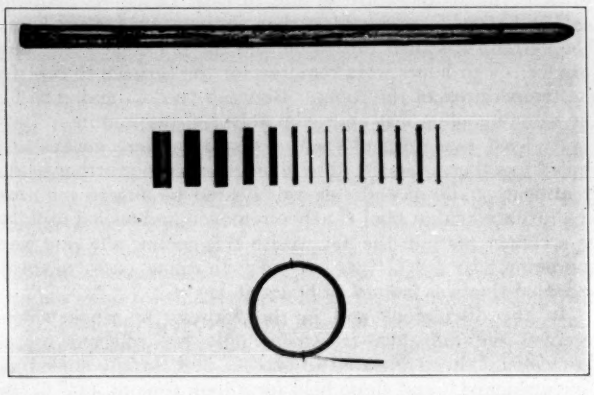


Composition diagram—Ni-Fe-Co series. Dots show compositions tested.

The alloys were cast from Armco iron, electrolytic nickel, and a very high grade of commercial cobalt containing only small amounts of impurities. They were melted together in the desired proportions in a silica crucible in a high frequency induction furnace. The metal was cast into bars 18″ long and ¾″ in diameter. The bars were rolled or swaged into ¼″ rods; then they were drawn into wire and flattened and trimmed into ⅛″ by .006″ tape. The material was annealed several times in the reduction process, for the cold working hardened the alloys rapidly and made them difficult to work.

To prepare the tape for heat-treatment and subsequent magnetic measurements, about 30 ft. of it was wound spirally into a ring of 3″ inside diameter, the ends being spot welded to the adjacent turns. Care was taken to wind the rings loosely to prevent the turns from sticking to each other during annealing.

FIG. 2.



Cast alloy bars and intermediate stages of samples in reduction to tape. Also ring from tape ready for heat treatment.

For convenient comparison of the magnetic properties of the alloys with those of the metals from which the alloys were cast, sample lots of the iron, nickel, and cobalt which we used in making the alloys, were melted, cast, and prepared in the same manner as the alloy test samples.

In Fig. 2 the various steps through which the alloys had to pass in the mechanical reduction to tape are shown. Between each step in the reduction, as indicated by a sample, the alloy had to be annealed to remove the mechanical hardness. A sample ring wound from the finished tape, ready for heat-treatment, is also shown in the figure.

The next step in the process of preparing these alloys for magnetic measurements is the heat treatment. Early experience with the nickel-iron alloys indicated the need for a

variety of such treatments, but of course it was impossible to apply to every alloy such a complete variety of heat-treatments, that all of the combinations of heat-treatment and composition could be known. Our procedure was to apply three types of heat-treatment.

A number of rings of a given composition were packed in a nichrome pot. The pot was placed in an electrical resistance furnace, the temperature of the furnace raised to between 900° and 1000° C. and held at that temperature for one hour. The current was then turned off and the pot cooled with the furnace. Ten hours were required for the furnace to cool to the temperature of the room. Between 700° C. and 400° C. the rate of cooling was approximately 1.5° per minute.

At least two rings of each composition were always annealed together. One of these rings received no further heat-treatment. The second ring was heated for fifteen minutes in a furnace held at 600° C., then removed and cooled rapidly on a copper plate in the air. With this cooling the rate was approximately 20° C. per second. In some cases a third annealed ring was heated 24 hours at 425° C.

In the discussions and in the figures, the rings which received the first heat-treatment only are referred to as "annealed," those reheated to 600° C. and rapidly cooled as "air-quenched," and those held for a long time at 425° C. as "baked." The magnetic measurements were made on these rings.

The magnetic induction, or flux density, was determined for a large number of magnetizing forces, beginning at a few hundredths of a gauss and increasing in uniform steps up to 100 gauss. Magnetization curves were plotted from these measurements. The induction was also determined for each composition at a magnetizing force of 1,500 gauss.

The permeabilities were computed from the induction measurements, and were plotted either against the flux density or the magnetizing force, depending on which graph illustrated best the characteristics of the material. At the lower ends these curves were extended to zero field strengths. Their intercepts on the permeability axis are the initial permeabilities. The maximum permeabilities were also obtained from these curves.

For determining hysteresis loss, two methods were used. In some cases hysteresis loops were plotted from ballistic measurements, and in other cases a direct determination of hysteresis loss was made from the apparent alternating current resistance of a winding wrapped around the sample. Ordinarily the hysteresis loop was obtained for one condition only in which the flux density was varied between plus and minus 5,000 gauss. For some of the alloys of special interest, a large number of loops were obtained for different magnetizations, the maximum flux densities varying from 100 or less to 5,000 gauss.

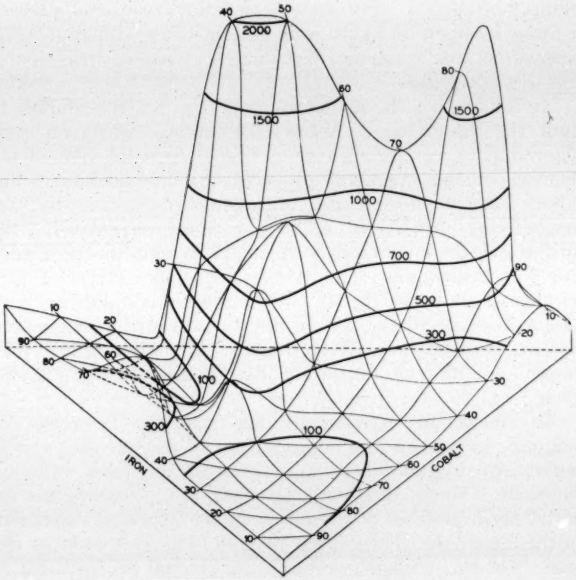
In illustrating the magnetic properties I will be forced to limit the discussion to a few outstanding values for each alloy, and by comparing these, obtain a general view of the relation of the magnetic properties to composition. The values I have selected are the intrinsic inductions for two magnetizing forces, 50 and 1,500 gauss respectively, the initial and the maximum permeabilities and the hysteresis loss for a maximum flux density of 5,000 gauss. For a number of alloys which represent regions of composition with magnetic properties of special interest, curves for magnetization and permeability will be shown. A number of hysteresis loops for different maximum flux densities will also be given.

In illustrating graphically the relations between the magnetic properties and compositions of ternary alloys, it is convenient to plot these quantities in the form of solid diagrams. Such a diagram is shown in Fig. 3 constructed for initial permeabilities of the alloys in the annealed condition. In this figure the composition triangle, Fig. 1, is used as the base. On this triangle, verticals are erected proportional to the numerical values of the initial permeability. The ends of these verticals give a contour of the upper face of the figure. With a sufficient number of alloys this surface represents fairly accurately the values of the initial permeabilities for all compositions. The edges of the surface give the initial permeabilities of the binary alloys and the rest of the surface those of the ternaries.

The coördinates of the composition triangle, the intersections of which give the compositions of the alloys in 10

per cent. variations, are projected to the surface and are represented by the narrow black lines. The heavy black lines on this surface are contours such as you see on topographical maps and represent the intersections with the surface of planes parallel to the base at definite elevations. Each line

FIG. 3.



Initial permeabilities for annealed alloys.

locates the compositions of those alloys which have equal values of initial permeability.

In this solid diagram of the initial permeabilities for the alloys in annealed condition, there are three regions of composition which are of special interest. The first of these is in the binary iron-nickel series represented by the back face of the diagram, which may be referred to as the nickel-iron

plane. The nickel percentage is indicated by the numbers at the intersections of the permeability coördinates with the surface. The left-hand corner represents 100 per cent. iron and the right-hand corner 100 per cent. nickel, with initial permeabilities of 250 and 200, respectively. Between these limits of composition the initial permeability varies from approximately 100 to more than 2,000. With small additions of nickel to iron the permeability drops gradually until the added amount is approximately 28 per cent. of the composition. From that point there is a rapid rise in the permeability with the increase in the nickel content reaching a maximum of over 2,000 for the alloy containing approximately 45 per cent. nickel. It then decreases as more nickel is added, reaching a second minimum of about 1,200 for 70 per cent. nickel and increases again reaching a second maximum of approximately 1,900 at 83 per cent. nickel.

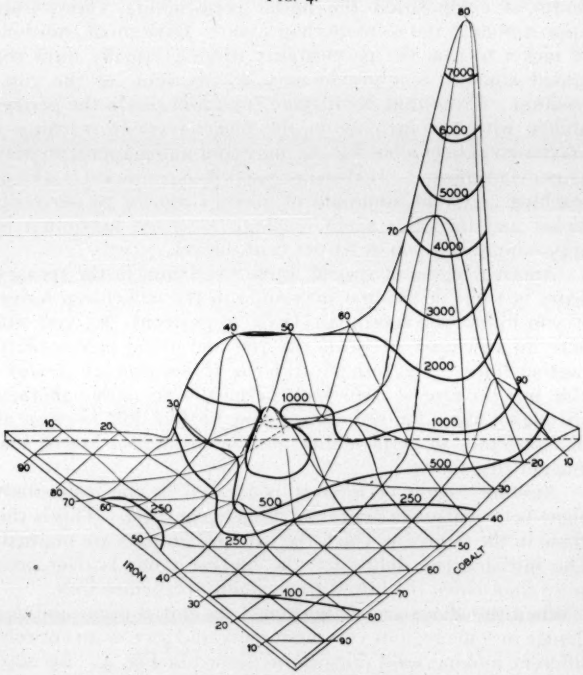
Another region of special interest is found in the ternary series in front of the first maximum in the nickel-iron series. If you follow the coördinate from 40 per cent. Ni, you will note an elevation between the 700 and 1,000 permeability contour lines. The ternary alloys of this region are remarkable not because of their high permeabilities although they are higher than for the surrounding region, but because of the constancy of permeability and low hysteresis loss at low magnetizing forces.

Another region of interest is located in the iron-cobalt plane between 40 per cent. and 70 per cent. iron. This is the plane in the figure on which the iron percentages are marked. The initial permeability for the highest point is over 600; more than twice the initial permeability of Armco iron.

When the alloys are air-quenched the initial permeabilities change in some regions very materially and give us an entirely different looking solid diagram as shown in Fig. 4. Because of the very high values of the permeabilities a different scale was used in this figure from that used in Fig. 3. It is interesting to note how the rapid cooling has affected some of the binaries in the iron-nickel plane. The rise in permeability begins at about 28 per cent., the same as for the annealed alloys, and the initial permeabilities are substantially the same, up to about 45 per cent. nickel. Between 45 per cent.

and about 90 per cent. nickel the permeabilities have increased to a remarkable degree. The valley we saw in the region 45 per cent. to 75 per cent. nickel for the annealed alloys has disappeared, and from 55 per cent. upward there is a rapid

FIG. 4.



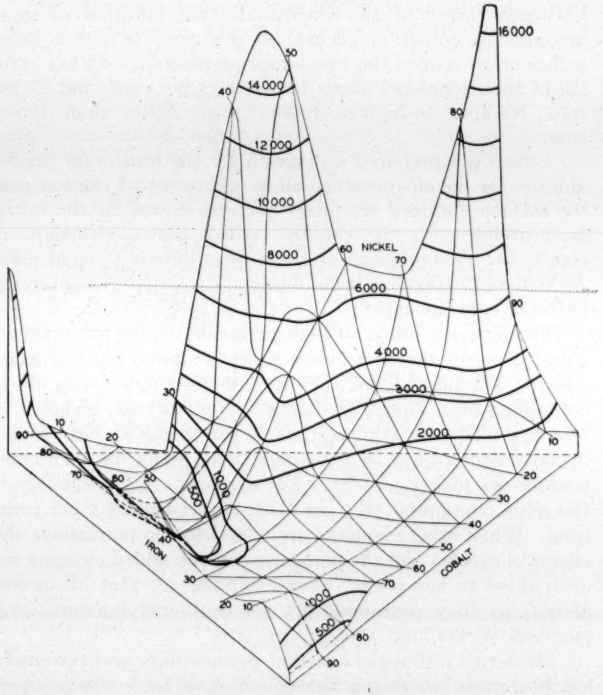
Initial permeabilities for air-quenched alloys.

increase reaching a peak value of approximately 8,000 for the composition containing 78½ per cent. nickel, an increase of over four times the permeability of the annealed alloy of the same composition.

Air-quenching also increases the initial permeabilities of

the group of ternary alloys which in the annealed condition showed a maximum characterized by a low hysteresis loss and a substantially constant permeability. This increase in permeability, however, is accompanied by a material increase

FIG. 5.



Maximum permeabilities for annealed alloys.

in the hysteresis loss at low flux densities and a decrease in the constancy of permeability.

In contrast to the alloys just discussed, the iron-cobalt series in the neighborhood of 50 per cent. iron gives a lower

permeability upon rapid cooling. In this respect they behave the same as iron and cobalt.

The maximum permeabilities for the annealed alloys shown in Fig. 5 give a surface very similar to that for the initial permeabilities. The most interesting difference is the rapid decrease in permeability of iron as indicated at the left-hand corner of the diagram by the addition of small amounts of cobalt or nickel, 10 per cent. of either being sufficient to reduce the maximum permeability 85 per cent. All of the iron-nickel alloys between 35 per cent. and 85 per cent. Ni have as high or higher permeability than Armco iron.

I have not prepared a diagram for the maximum permeabilities for the air-quenched alloy. However, I can say that the surface obtained resembles the one shown for the initial permeabilities for the rapidly cooled alloys, although, of course, the maxium permeabilities are of different magnitudes. As high as 120,000 has been obtained for the alloy containing 78½ per cent. nickel.

The group of alloys of high permeability for low magnetizing forces in the iron-nickel series we have named permalloy.[1] The permalloys, therefore, include nickel-iron alloys containing more than approximately 30 per cent. nickel. In referring to specific compositions in this group we have found it convenient to use as a distinguishing prefix for each composition its nickel content. For example, 78.5 permalloy is the alloy containing 78.5 per cent. nickel and 21.5 per cent. iron. When other elements are added to the permalloys the chemical symbol and the percentage of the added element are also added to the prefix. For example, 3.5–78.5 Mo-permalloy is an alloy containing 3.5 per cent. molybdenum, 78.5 per cent. nickel, and 18 per cent. iron.

The ternary alloys of constant permeability and extremely low hysteresis loss at low flux densities we have also grouped together under a common name, perminvar.[2] The limits of composition for the perminvars are less easily defined than for the permalloys, because the transition in magnetic proper-

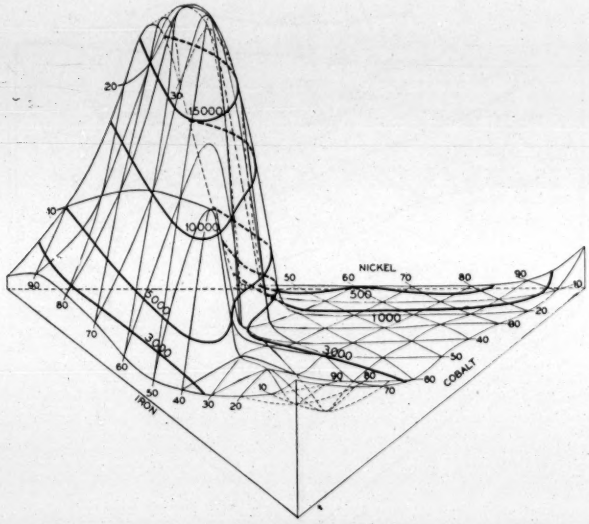
[1] Arnold and Elmen, JOURN. OF FRANKLIN INST., May, 1923, p. 621.

[2] G. W. Elmen, JOURN. OF FRANKLIN INST., Sept., 1928, p. 317.

ties is not as marked with small changes in composition. We have found that compositions between 10 per cent. and 40 per cent. iron, 10 per cent. and 80 per cent. nickel, and 10 per cent. and 80 per cent. cobalt have marked perminvar characteristics.

The hysteresis losses of the alloys in the annealed condition are plotted in Fig. 6 for a maximum flux density of

FIG. 6.

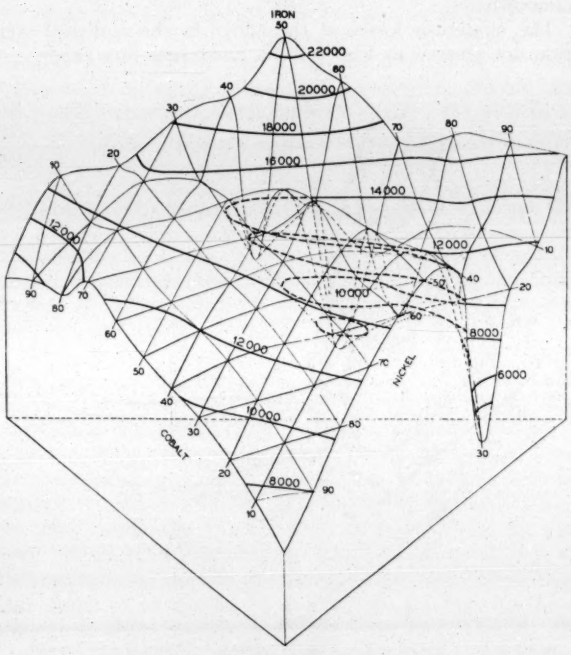


Hysteresis losses, ergs per cm.³ per cycle, for maximum flux density of 5,000 gauss for annealed alloys.

5,000 gauss. This diagram illustrates again the abrupt change in the magnetic properties as we pass from alloys with large iron content to those in which nickel predominates. In this figure the lowest energy losses are those for alloys in the neighborhood of the 78.5 permalloy composition. In the iron-cobalt series the 50 per cent. cobalt alloy has the lowest hysteresis loss.

The intrinsic inductions, which are those parts of the inductions contributed by the magnetic material, are shown in Fig. 7 for a magnetizing force of 50 gauss. In the figure

FIG. 7.



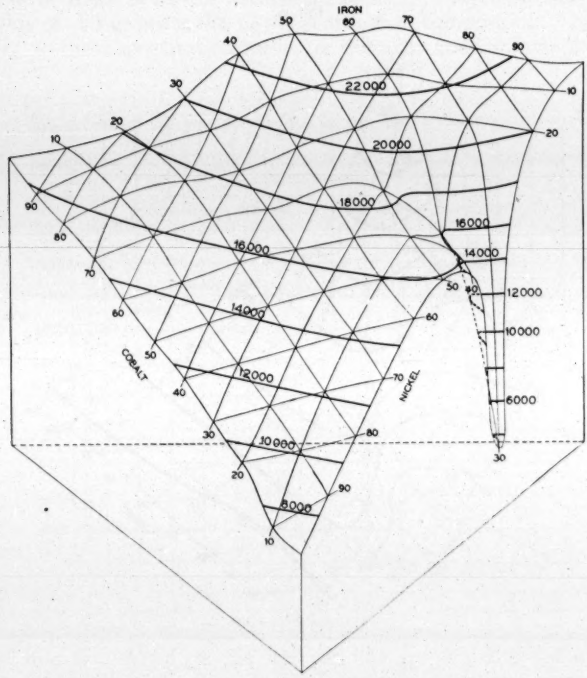
Intrinsic inductions for annealed alloys at $H = 50$.

the triangle has been turned through 120° clockwise from its position in the previous figures, placing the iron-cobalt alloys in the back of the diagram. For this magnetization the 50 per cent. iron-cobalt alloy is superior to any of the others.[3] Another interesting part of this diagram is the deep depression

[3] This was also found by Ellis, Engineering and Science Series No. 16, June 1927, Rensselaer Polytechnic Institute.

at about 30 per cent. nickel, in the iron-nickel plane—now the right-hand front face of the diagram. This depression extends back for some distance into the ternary alloys.

FIG. 8.

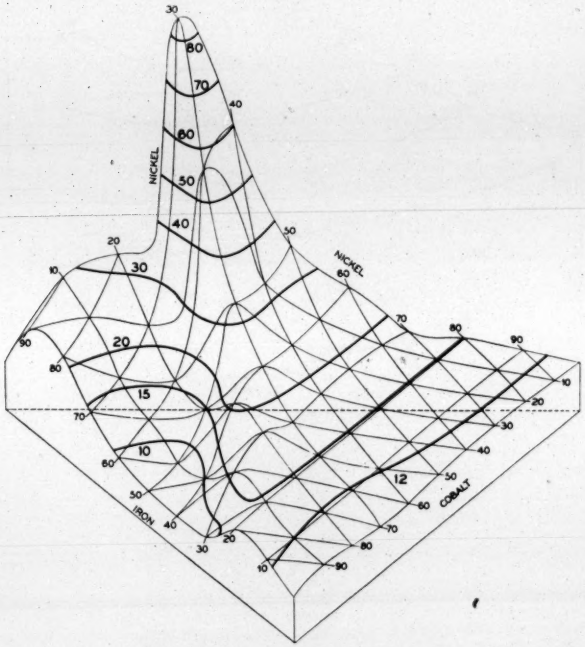


Intrinsic inductions for annealed alloys at H = 1,500

The intrinsic inductions are also shown for a magnetizing force of 1,500 gauss in Fig. 8. Here we find that the irregularities of the surface in the previous figure have largely disappeared and the surface has become fairly flat. The inductions for the alloys in the neighborhood of 34 per cent. cobalt and 66 per cent. iron have now increased so that they

are practically the same as for the 50 per cent. composition. The valley in the neighborhood of 30 per cent. nickel has largely disappeared except for the alloys without cobalt which are much harder to saturate.

FIG. 9.

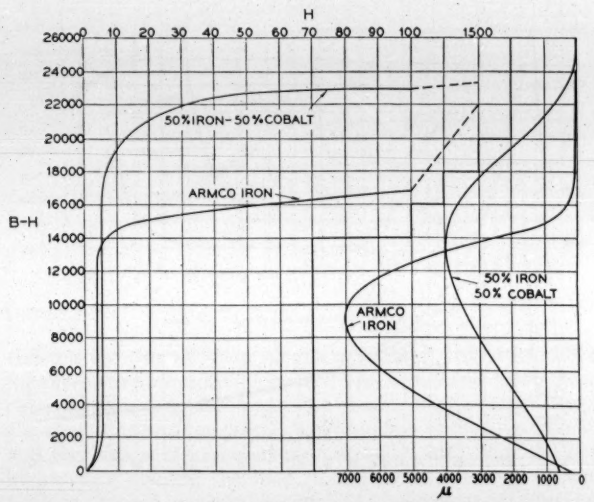


Resistivities, microhm-cm., for annealed alloys.

In Fig. 9 a solid diagram has also been constructed for the resistivity of these alloys in the annealed condition. It is interesting to note the high resistivities of some of the nickel-iron alloys—again in the back of the diagram—and the low values for some of the cobalt-iron alloys in the 45 per cent. to 70 per cent. cobalt range of compositions.

In the discussion of the magnetic properties of these alloys, I have pointed out that there are three regions of composition which are of special interest from the standpoint of applications because of their unusual magnetic properties. One of these is in the iron-cobalt series. A representative alloy of this group is the 50 per cent. cobalt composition. In Fig. 10 the magnetization curves for this alloy and for a sample

FIG. 10.



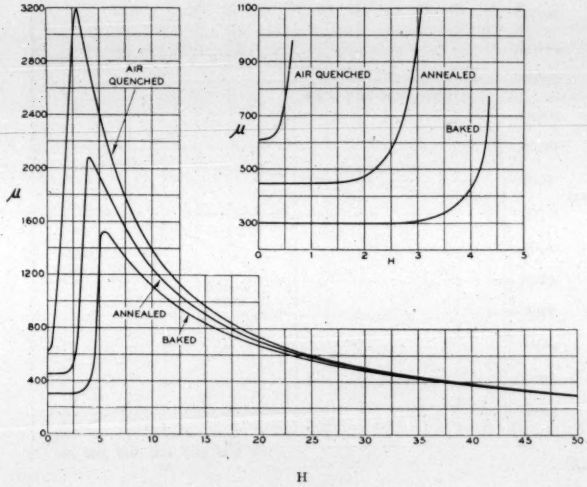
Magnetization and permeability curves for the 50 per cent. iron, 50 per cent. cobalt composition and for Armco iron.

of iron are shown on the left and the permeability curves plotted against the same scale of intrinsic inductions on the right. The scale for the magnetizing force of the magnetization curve is at the top of the figure. Below an induction of 1,000 and above 13,000 the permeability of the alloy is higher than for iron. Its initial permeability is 600 and the maximum permeability is 4,000. For a magnetizing force of 100 gauss the intrinsic induction is nearly 23,000 gauss. For Armco iron the initial and maximum permeabilities are 250

and 7,000, respectively, and the intrinsic induction for a magnetizing force of 100 gauss is 17,000.

The perminvars are the next group with interesting characteristics. Their remarkable constancy of permeability at low magnetizing forces and their extremely low hysteresis loss at low flux densities make them of unusual interest. The composition 45 per cent. nickel, 25 per cent. cobalt and 30 per

FIG. 11.



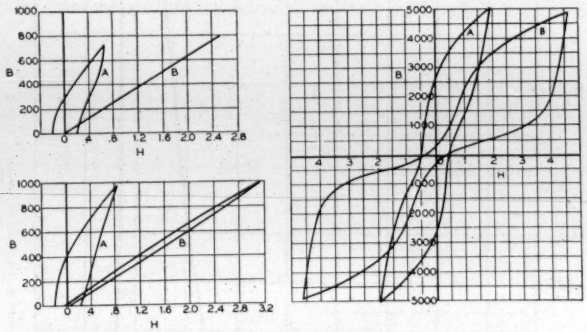
Permeability curves for a perminvar alloy of 45 per cent. Ni, 25 per cent. Co, 30 per cent. Fe.

cent. iron is a typical alloy for this group. Permeability curves for this alloy for three types of heat-treatment are plotted against magnetizing force in Fig. 11. The insert in the upper right-hand corner shows the lower parts of these curves plotted to a larger scale. For the baked alloy the permeability is constant at 300 with an increase of the magnetizing force from zero to $2\frac{3}{4}$ gauss. The initial permeability for the air-quenched alloy is more than twice that of the baked, but the constancy of permeability is a great deal less. This illustrates

the close relation of these two properties. As the magnetizing force approaches 40 gauss the differences in the permeabilities, resulting from different rates of cooling, disappear.

The hysteresis loops for this composition are also of unusual interest. Fig. 12 illustrates the hysteresis charac-

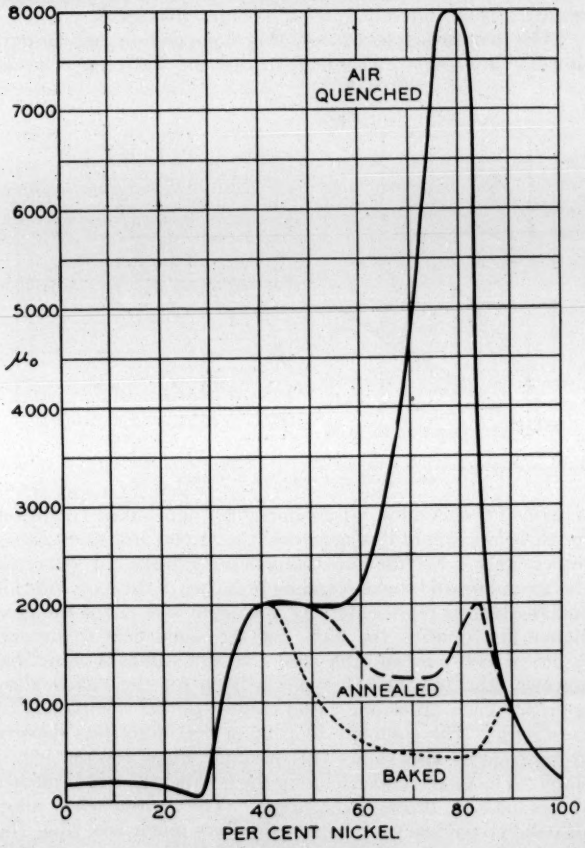
FIG. 12.



Hysteresis characteristics for a perminvar alloy containing 45 per cent. Ni, 25 per cent. Co, 30 per cent. Fe. A = air-quenched; B = baked.

teristics for this alloy, in air-quenched and baked condition, for three maximum flux densities, 750, 1,000 and 5,000 gauss, respectively. For the lowest flux density of the baked sample the ascending and the descending branches of the loop coincide and the loop is represented by a straight line. For the next higher flux density the loop, for the same heat-treatment, begins to have a measurable area. At low values of induction, however, the two branches of the loop for the baked alloy approach each other and often come together completely at the origin. The complete loop for a maximum flux density of 5,000 gauss also shows this peculiar shape for the baked alloy. The loop is constricted in the middle, the two branches almost passing through the origin. The air-quenched alloy also shows tendency of constriction but much less than the baked. The areas of the two loops show that for this value of maximum flux density the hysteresis loss for the baked sample is greater than for the air-quenched. This condition is the reverse of that for lower flux densities.

FIG. 13.



Initial permeabilities for the Fe-Ni series.

The last group of alloys of special interest are the permalloys. In Fig. 13 I have taken the curves for initial permeabilities of the iron-nickel series from the solid diagrams for the air-quenched and the annealed conditions and plotted them on the same scale of coördinates. A curve of initial permeabilities for a series of baked alloys is also plotted in this figure. The baking process for these alloys differed from the one we usually employed in that each alloy was baked

FIG. 14.

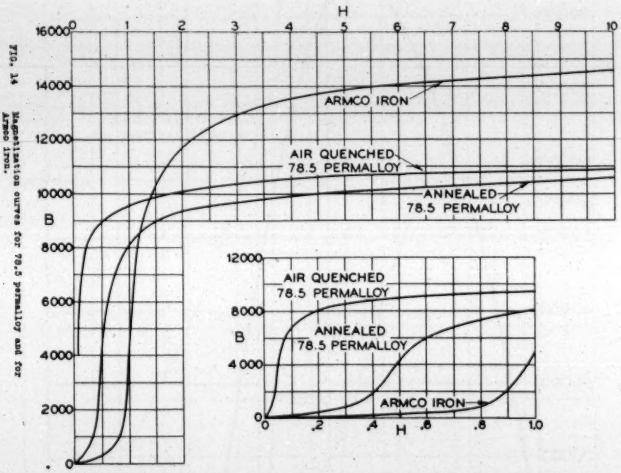


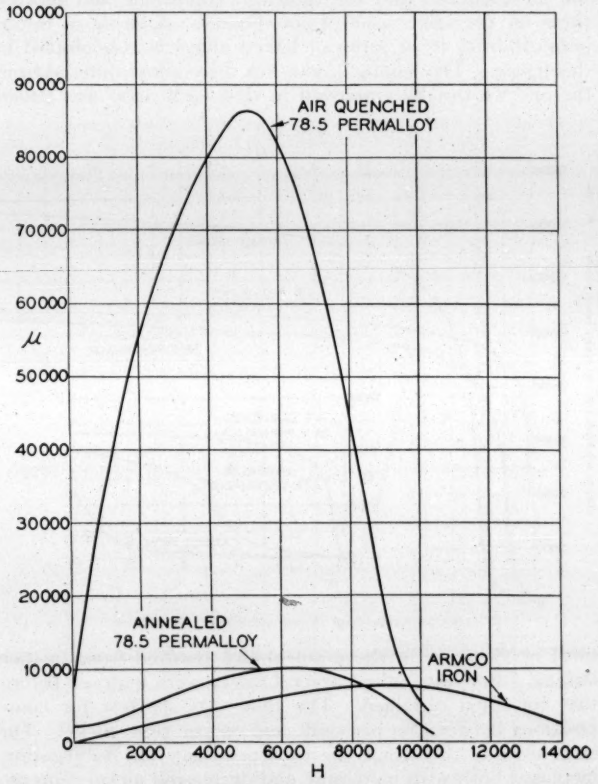
FIG. 14 Magnetization curves for 78.5 permalloy and for Armco iron.

Magnetization curves for 78.5 permalloy and for Armco iron.

until no decrease in the permeability resulted from further baking. For some alloys several weeks were required before this condition obtained. The time was shortest for compositions between 60 per cent. and 80 per cent. nickel. On both sides of this range the time necessary for stabilization increased both with increasing and decreasing nickel content. With nickel content of less than 42 per cent. and more than 88 per cent., approximately, no difference sufficiently large to be attributed to the baking could be observed, even after the alloys had been baked for several weeks.

The 78.5 permalloy composition in this series is of special interest because this alloy when air-quenched gives the highest

FIG. 15.

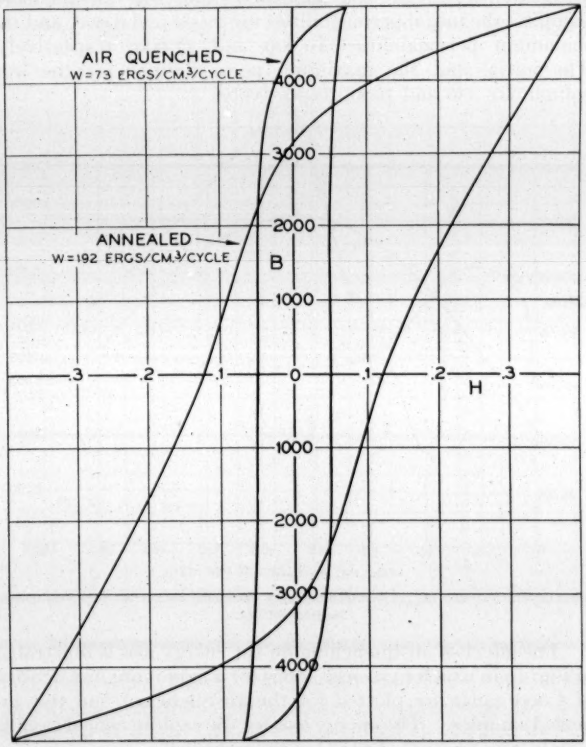


Permeability curves for 78.5 permalloy and for Armco iron.

initial and maximum permeabilities. The magnetization curves for this composition are plotted in Fig. 14 for annealed and air-quenched samples, and for a sample of

annealed iron. The lower part of this graph is shown in the insert on a larger scale. The curves are plotted for magnetizing forces between 0 and 10 gauss only. In these curves the

FIG. 16.



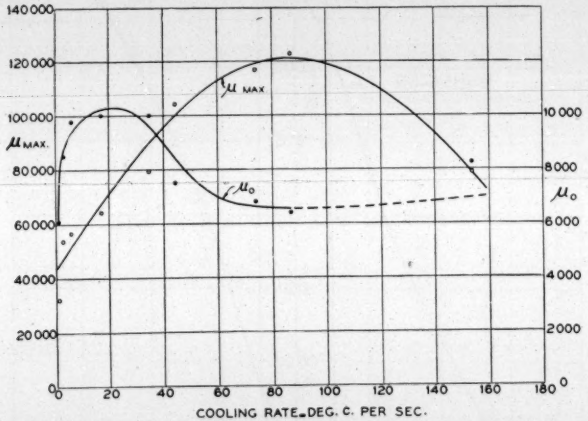
Hysteresis loops for 78.5 permalloy.

induction for the annealed sample remains lower than for the air-quenched sample, but as the force increases there is a tendency for the two curves to approach each other. This

continues with still further increase in the magnetizing force and beyond 50 gauss the two curves coincide.

The permeability curves for these samples are plotted in Fig. 15, illustrating the great difference in their maximum permeabilities. For the annealed and the air-quenched samples, the initial permeabilities are 2,000 and 9,000, and the maximum permeabilities 10,000 and 87,000, respectively. The initial and the maximum permeabilities for the iron sample are 250 and 7000, respectively.

FIG. 17.



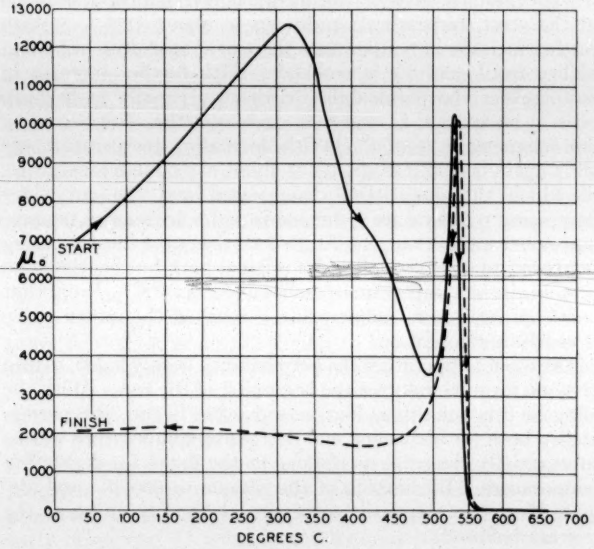
Initial (μ_0) and maximum (μ_{max}) permeabilities for 78.5 permalloy for different rates of air-quenching from 600° C.

The effect of air-quenching on the energy loss is illustrated in Fig. 16 in which hysteresis loops for a maximum flux density of 5,000 gauss are plotted for the air-quenched and the annealed samples. The energy loss for the rapidly cooled sample is only 35 per cent. of that for the annealed.

In deciding on a rate for air-quenching we selected the rate which gave the highest initial permeability for the 78.5 permalloy. In Fig. 17 I wish to illustrate how small changes in this rate affect the initial and the maximum permeabilities

for this composition. The scale for maximum permeability is on the left and for initial permeability on the right. The cooling rate is in degrees centigrade per second. It is interesting to note that the highest initial permeability was obtained when the cooling rate was approximately 20° C. per second, while a rate four times as rapid gave the highest

FIG. 18.



Temperature-permeability curve for 78.5 permalloy: magnetizing force .003 gauss.

maximum permeability. 10,000 and 120,000 were the highest initial and maximum permeabilities, respectively, for these particular samples. These values are not the highest we have obtained for this composition. Test samples from other castings have given as high as 13,000 for initial permeability and upwards of 400,000 for maximum.

Fig. 18 illustrates the manner in which the permeability at a low magnetizing force for a rapidly cooled 78.5 permalloy

composition is affected by passing it through a temperature cycle between room temperature and 650° C. The permeability was measured for a constant magnetizing force of .003 gauss as the temperature was passed through this cycle. The rate at which the sample was heated and cooled was rather slow, requiring upwards of two hours to complete the heat run.

The permeability of the air-quenched sample was 7,000 at the start, increasing rapidly up to about 315° C. With further increase in temperature there is a rapid drop in permeability until 500° C. is reached. With further increase in temperature the permeability rises very rapidly to a sharp peak at about 530° C. and then decreases, the alloy becoming non-magnetic at 590° C. With decreasing temperature the alloy again becomes magnetic at about the same temperature, at which the magnetism disappeared and the curve for decreasing temperature is the same as for increasing temperature over a short range. At 500° C. the curve for decreasing temperature does not follow its original path but continues to drop until the temperature reaches about 425° C. From that point on until room temperature is reached the return curve is nearly horizontal.

At room temperature the permeability is only 2,000, a drop of 5,000 from its value at the beginning of the run. With the alloy in this condition, if a second cycle is run, the permeability both for increasing and decreasing temperature will be substantially the same as the one in the figure for decreasing temperature. By heating of the sample to 600° C. and air-quenching, the magnetic properties at the beginning of the test are restored.

The connection between the permeability of this composition and the heat treatment in the temperature range below 600° C. is also illustrated by a series of tests in which annealed rings were air-quenched from temperatures below 600° C. The rings were placed in a furnace and heated at 600° for fifteen minutes. The temperature was then decreased slowly to 550° C. and held until the alloys had reached a constant condition. One of the samples was then taken out of the furnace and air-quenched. The temperature of the furnace was then dropped another step and the process of

stabilization and air-quenching repeated for the next ring. This was repeated for a number of temperatures until there was substantially no change between two rings quenched from successive temperatures. Another series of annealed rings was slowly heated in successive steps to the same temperatures, stabilized, and then air-quenched.

A comparison of the initial permeabilities of these rings showed that each ring attained a definite permeability, characteristic of the temperature from which it was air-quenched whether it reached that point from a lower or a higher temperature, provided it was stabilized before air-quenching. The air-quenched rings stabilized between 500° and 400° C. showed the greatest change in permeability. The time required for stabilization at the higher temperatures was very short, only a few minutes being required in the neighborhood of 500° C., but it increased progressively as the temperature was lowered, and in the lower end of the range several days were required for the alloy to reach a constant condition.

Tests on other compositions showed that those alloys in which the magnetic properties depended on the rate of cooling below 600° C. gave results similar to those for the 78.5 permalloy. The temperature range was also found to be substantially the same as for the 78.5 permalloy, although in some cases there were indications that small changes occurred above 600° and below 400° C.

This connection between heat treatment and magnetic properties led me to conclude that the differences in these properties in the alloys which had been heat-treated differently below 600° C. were caused by constitutional changes in the alloys. Such changes are common in alloys in the solid state, often at low temperatures. The progressive change in the permeability as the temperature of the alloy decreases slowly below 600° C., the gradual increase in the time required for a change to complete itself as the temperature drops, and the prevention of the change by rapid cooling through this temperature range support this conclusion.

It is well known that some alloys are in the state of homogeneous solid solutions at high temperatures, but segregate into two or more phases as the temperature drops.

Such segregation ordinarily takes place in a definite temperature range, and is progressive in nature. It is a change of this type which I picture as taking place in these alloys during slow cooling. At the upper end of the critical temperature range for each alloy, the homogeneous solid solution begins to segregate into constituents of different composition. This segregation continues until the temperature has dropped to a point where no further changes take place. Rapid cooling prevents this segregation and the alloys remain after cooling in a metastable condition.

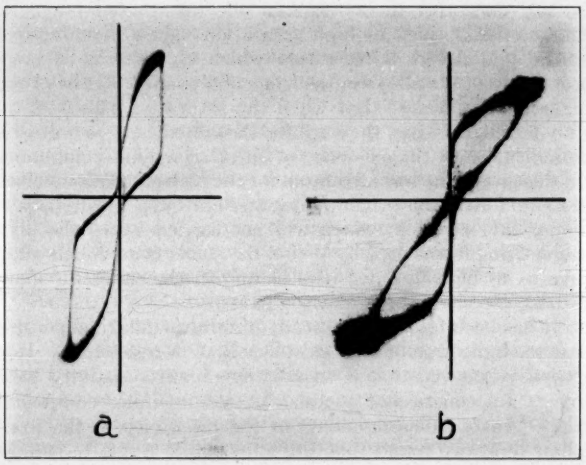
We would suppose that if such a change takes place, confirmatory evidences might be found. I shall refer, briefly, to some of our attempts to obtain evidence to confirm our speculations as to the nature of these magnetic changes.

The resistivity was measured for rapidly cooled and for baked alloys both of permalloy and perminvar compositions. These measurements showed that for both types of alloys, baking reduced the resistivity. For example, the resistivity of a 78.5 permalloy sample was measured after annealing and after air-quenching. The resistivities for the two conditions were 14.2 and 15.8 microhm-cm., respectively. Upon reannealing the resistivity again dropped to 14.5, about the same as before it was air-quenched. This change is in accordance with what would be expected if a segregation took place with annealing. A homogeneous solid solution has the highest resistivity and segregation tends to lower it.

Other interesting evidence is obtained from the study of the hysteresis loops. For the perminvar alloys the constricted loops are very marked and easily produced. In the permalloys containing between 60 and 80 per cent. nickel also there is a tendency to constriction in the slowly cooled alloy, not so marked but sufficiently prominent to lead me to believe that the same general changes occur in both groups of alloys, differing only in the nature of the segregates and the ease with which segregation occurs. Now we know that homogeneous magnetic materials have a characteristic type of hysteresis loop. For such materials there is no constriction in the middle, but the widest part of the loop is generally at that point. We also can construct hysteresis loops which have constrictions by making up cores of several materials in a

parallel or parallel-series arrangement.[4] This is illustrated by the hysteresis loop *b* in Fig. 19. This loop is traced by a cathode ray oscillograph for a bi-metallic rod, 15″ long consisting of a core of .04″ diameter unannealed piano wire and a .006″ wall permalloy tube, heat-treated to give high permeability and fitting closely to the wire. Curve *a* is a loop similarly traced for a perminvar core. Though the magnetic circuit conditions for the two cores are not the

FIG. 19.



Hysteresis loops: *a*, perminvar (45 per cent. Ni, 25 per cent. Co, 30 per cent. Fe); *b*, bi-metallic rod. Loop traced with cathode ray oscillograph.

same, the marked similarity of the two loops favors the view that the constricted loop of the perminvar results from segregation.

It is interesting to note in this connection that the examination by X-ray crystal analysis methods of these alloys has not given evidence of a segregation such as other evidence leads me to think must occur. Perhaps the reason for this is

[4] E. Gumlich, *Arch. f. Elektrotechnik*, Vol. 9, p. 153, 1920.

that the different constituent metals are so closely related that small changes in the structure cannot be detected by this means, or perhaps the reason is that the size of the groups of atoms making up the constituents is too small to be detected by X-ray methods.

While the variation in the permeability and in the other magnetic characteristics which could be affected by heat treatment may be explained by the theory of segregation, this theory does not explain why these alloys have such high permeabilities at low magnetizing forces.

Nor does this theory explain the unexpected magnetic characteristics, such as high saturation values of induction, or the low electrical resistance which characterize a large proportion of the alloys in the iron-cobalt series. It has been suggested by Weiss [5] that when the saturation values of an alloy are higher than they are for the constituent metals it is an indication of the existence of an intermetallic compound. On this ground he has accounted for the high saturation values he found for an iron-cobalt alloy containing 34 per cent. cobalt. In our investigation, which was not carried up to the high magnetizing forces used by Weiss, the 50 per cent. cobalt alloy gave us as high flux densities as any in the series for magnetizing forces upwards of 1,500 gauss.

It has been found in the study of intermetallic compounds that one indication of their existence is a low resistivity. It is generally believed that if an alloy has lower resistivity than any of its constituent metals, an intermetallic compound exists. In our measurements of the resistivity of the iron-cobalt series we found that the alloys with lowest resistance were those containing between 25 per cent. and 60 per cent. iron. There is a rather abrupt decrease in the resistivity as the percentage of iron increases beyond 25 per cent. Beyond 50 per cent. iron there is a gradual increase with a maximum at about 85 per cent. iron. From these measurements we would conclude that if an intermetallic compound exists, it is of a higher cobalt percentage than that suggested by Weiss. From our measurements of the resistivity of the alloys in this series the most probable intermetallic compound would be

[5] *Transactions of the Faraday Society*, Vol. 8, p. 149.

one containing approximately 66 per cent. cobalt of the chemical formula $FeCo_2$.

The data which I have presented are those for the compositions of iron, nickel and cobalt. In addition to these alloys, we have studied the effects of adding non-magnetic elements to numerous alloys of particular compositions. I cannot at this time go into a detailed discussion of the results with these, but I shall mention briefly some of them. We found that the addition of some of the non-magnetic metals to both the permalloys and ther perminvars made those alloys less sensitive to heat treatment. The resistivity was also generally increased. For some compositions the addition in small percentages of a non-magnetic metal, particularly chromium and molybdenum, increases the permeability at low magnetizing forces. This is illustrated in Fig. 20 where I have plotted the permeability curves for Armco iron, 78.5 permalloy, and a 3.5–78.5 Mo-permalloy. You will note that the initial permeability of the molybdenum-permalloy alloy is 21,000 as compared with 9,000 for the permalloy without molybdenum. As a rule the maximum permeability was generally decreased when a non-magnetic element was added and so were the saturation values of induction.

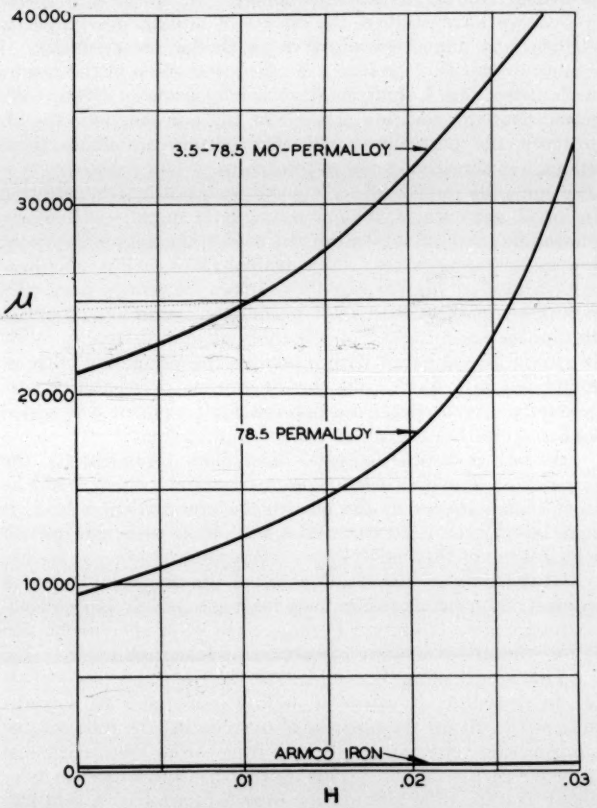
As our investigation was undertaken primarily for the purpose of searching for magnetic materials which could be used to advantage in the electrical communication field, it may be of interest to describe a few of the principal uses to which some of these alloys have been put.

Of the three groups of alloys which are of special technical interest, the permalloys are now used extensively in electrical communication circuits. Perhaps their most spectacular use is for continuous loading of submarine telegraph cable.

The term loading is used in the electrical communication art to designate a system of adding inductance to a transmission circuit for the purpose of overcoming the unfavorable transmission characteristics resulting from the electrical capacity of the circuit. This system has been used in telephone transmission circuits for over a quarter of a century. The standard method used for telephone circuits, in which inductance coils are placed at equally spaced intervals along the transmission line, was not considered practical for deep sea

cables. The only suitable method from a mechanical standpoint was a continuous loading in which a magnetic material

FIG. 20.



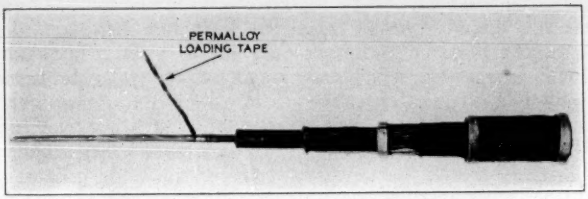
Permeability curves for permalloys.

is distributed uniformly along the whole length of the cable. Before permalloy was developed the best magnetic material

available was iron. It could not be used economically for long submarine cables because of its low permeability. With permalloy having between 40 and 50 times the permeability of iron in the range of magnetic field strength encountered in such cables, it was found that beneficial results could be attained and cables of more than five times the carrying capacity of the old type could be built.

The first permalloy loaded submarine telegraph cable was laid in 1924 between New York and the Azores, a distance of approximately 2300 nautical miles. A sample of the deep sea section of this cable is shown in Fig. 21. Numerous other

FIG. 21.

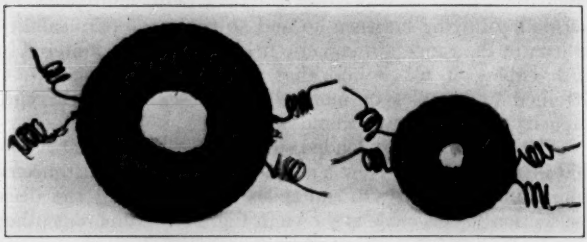


Sample of submarine loaded cable, showing the loaded conductor.

loaded cables have been laid since 1924; the total mileage of loaded submarine telegraph cables is now upwards of 16,000 nautical miles.

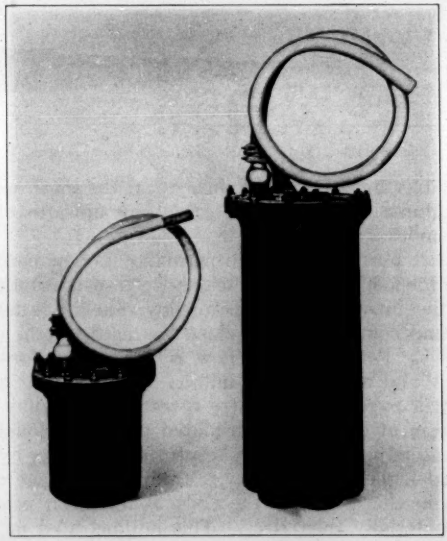
Another purpose for which permalloy is now used extensively is for loading coils for telephone transmission circuits. Before the introduction of permalloy, finely powdered, insulated and compressed iron dust was used for the cores of these coils. Permalloy has now replaced iron for loading coil cores, and upwards of a million cores per year are used by the Bell System. For these cores the permalloy is used in the form of compressed insulated powder. Some of the advantages in using permalloy result from its lower hysteresis losses and higher permeability. Taking advantage of these qualities in the design of the coils, it has been possible to reduce materially their sizes. This is illustrated in Fig. 22 where two standard loading coils for use in the same circuits are shown. One of these has a permalloy core and the other

FIG. 22.



Compressed powdered core loading coils: left, electrolytic iron core; right, permalloy core.

FIG. 23.



Cast-iron cases each containing 200 loading coils: left, permalloy core coils; right, iron core coils.

a core of iron. The former is approximately ⅓ the size of the latter.

When these coils are used in service usually a large number are placed in containers which are placed at different points in manholes or on poles along the telephone circuits. In Fig. 23 two such iron cases with their cable connecting stubs are shown; each contains 200 coils. The small case contains the permalloy coils, and the large case the iron core coils. The use of permalloy has reduced the combined weight of the coils and the cases from approximately 1,700 lb. to about 700 lb.

Another use of permalloy in the telephone plant has been found in the case of relay cores. Relays are used to connect and disconnect mechanically the telephone circuits at the central office and at other points. These relays are magnetically operated and their efficiency depends largely on the magnetic quality of the core material. Certain groups of these relays are required to operate under very severe circuit conditions where the operating currents are small and where the relays are required to distinguish between very small changes in current values. For such circuits, relays with permalloy cores are now used extensively.

The permalloy alloys are also used extensively for cores in high quality audio transformers, in telephone receivers, and earphones, and in electrical measuring instruments.

The permalloy series was first developed, and is also the one which was first used, for commercial purposes on a large scale. The other alloys are still in the commercial development stage, but interesting results have been obtained which make us feel confident that both the perminvars and the iron-cobalt alloys will take their places beside permalloy as important magnetic materials in electrical communication.

The Rate of Emission of Alpha Particles from Radium. (*Proc. Roy. Soc.*, A 787.) H. J. J. BRADDICK and H. M. CAVE. The number of alpha particles emitted by a unit mass of radium in unit time is quite an important constant in the interpretation of radioactive changes, especially where energy relations are involved. The heat evolved by radium is in the main accounted for by the energy of the α particles and of the recoil atoms. When the quantity of heat is calculated it is found that all of it is not accounted for, provided use is made of the experimentally determined rate of emission of α particles. This investigation is undertaken with the intent of securing an entirely reliable determination of this rate. It is found that one gram of radium in one second emits 3.68×10^{10} alpha particles. Geiger and Werner recently publish as their result 3.40×10^{10} while Rutherford and Geiger obtained 3.57×10^{10}. When the new result is used for the calculation of the heat developed excellent agreement is seen between the calculated and the experimentally obtained quantities of heat. G. F. S.

Visible Radiation Characteristics of Incandescent Oxides. MARCELLA L. PHILLIPS. (*Physical Review*, Nov., 1928.) A study was made of the visible radiation characteristics of urania, ceria, lanthana, neodymia, erbia, yttria, zirconia, thoria, alumina, beryllia, magnesia and of certain mixtures. These were heated to red brightness temperatures ranging from 1,400 to 2,000° K. and the total emission at each temperature in candles per sq. cm. and the blue brightness in terms of the blue brightness of the black body at the temperature of melting palladium are tabulated. At the lowest observed temperature of 1,400° K. a black body has a blue brightness of .0061. The following substances have values of this quantity lying between .006 and .01, viz., tungsten, urania, ceria neodymia, lanthana, zirconia, thoria, and beryllia. At the temperature considered magnesia has the greatest blue brightness, .071. Magnesia has also the greatest emission per sq. cm., viz., about one candle per sq. cm. This becomes 79 at 2,000° K., but at that temperature it is exceeded by alumina and beryllia. Elevating the temperature from 1,400° to 2,000° K. produces the largest relative increase in radiation per sq.cm. in the case of yellow ceria where the emissions at the respective temperatures are .36 and 88.0. For a black body the values for the two temperatures are .26 and 44.0. G. F. S.

COSMIC RADIATION AND RADIOACTIVITY.

BY

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BARTOL RESEARCH FOUNDATION
Communication No. 37.

In 1898 S. Currie [1] suggested that there may exist in all space some unknown highly penetrating radiation which is capable of being absorbed by the elements of high atomic weight. This radiation would manifest itself by its secondary radiations in the form of Becquerel rays. Later Perrin [2] proposed a theory of radioactivity in which he assumed that the atoms of the radioactive elements are capable of absorbing ultra penetrating radiation which passes unabsorbed through non-radioactive elements. Experiments which have afforded a test of this theory are those in which an investigation is made in order to determine if the rate of decay of a radioactive substance is altered by placing it underground where it will be shielded from cosmic radiations. Elster and Geitel [3] have measured the activity of Joachimisthal (a uranium ore) in a mine at a depth of 500 meters and found that its activity remained constant. Piccard and Stahel [4] have found no change in the activity of UX when left in the Simplon tunnel for two months at a depth of 2,200 meters. Also A. H. Compton and Hagenow lowered a tube of radium emanation to the bottom of the Calumet Heckla Mine in northern Michigan. After allowing it to remain there for a period of two weeks it was compared with a similar tube which had been left in the laboratory for the same length of time. Their results were not published, but Prof. Compton has informed the writer that their measurements showed no greater change of the activity of the two specimens than about two per cent in the remaining activity of the emanation. This difference was of the same order as the experimental error.

In the present work a radioactive substance was taken to the bottom of a mine where its activity was measured. These results were then compared with previous measure-

ments which were taken while the substance was at the top of the mine. The specimen which was chosen for the investigation was polonium because of its relatively short half-value period and its simple transformation. The most accurate of the experiments which have been mentioned above are those of Piccard and Stahel. They prepared four specimens of UX and for a period of two months they were left in the following places: the first at Zurich (500 m. alt.), the second at Brigue (680 m. alt.), the third at Junfraujoch (3,500 m. alt.) and the fourth in the Simplon tunnel under 2,200 m. of rock. The measurement of the relative intensity of the specimens were made at Zurich before and after the exposures and were found to differ by not more than one-tenth of one per cent. If we assume the fundamental postulate of radioactivity the method used in the present work is equivalent to that of Piccard and Stahel. The great difference between the two experiments is the entirely different measure of transformation which it concerns. The UX used by Piccard and Stahel emitted β and γ rays while in the present work α particles are the primary agent involved.

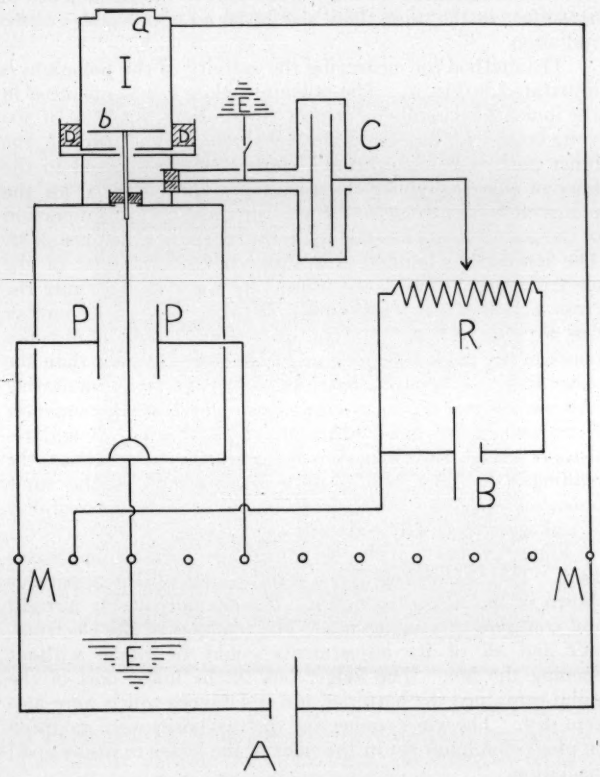
The polonium was taken 1,150 feet below the surface to the bottom of the zinc mine (owned by the New Jersey Zinc Company) at Franklin, New Jersey. The mine contained a large amount of Willemite (Zn_2SiO_4) and in order to calculate the absorption of cosmic radiation for this depth of Willemite in terms of water or lead we can use the following formula of Klein and Nishmia:

$$\mu = \frac{2\pi Ne^4}{m^2c^4}\left\{\frac{1+\alpha}{\alpha^2}\left[\frac{2(1+\alpha)}{1+2\alpha} - \frac{1}{\alpha}\log(1+2\alpha)\right] + \frac{1}{2\alpha}\log(1+2\alpha) - \frac{1+3\alpha}{(1+2\alpha)^2}\right\},$$

where μ is the absorption coefficient. N the number of electrons per cc. which produce scattering, i.e. $N = ZL\rho/A$ where Z is the atomic number, ρ the density, A the atomic weight and L Loschmidts number (the number of atoms per gram atom). m is the mass of the electron and e its charge. $\alpha = \frac{h\nu}{mc^2}$ where ν is the frequency of the cosmic radiation.

Thus for a given frequency the absorption depends directly upon the number of electrons of the atom which produce

FIG 1.



Experimental Arrangement.

scattering. From this equation we find that the ratio of μ for lead to that for Willemite is 2.8 for any given frequency. Thus 1,150 feet of Willemite should absorb as much of the

cosmic radiation as would about 400 feet of lead or 3,200 feet of water. Since Millikan has found that it only requires approximately 68 meters of water to absorb practically all of the cosmic radiation we are lead to believe that at a depth of 1,150 feet in the mine there should be no appreciable cosmic radiation.

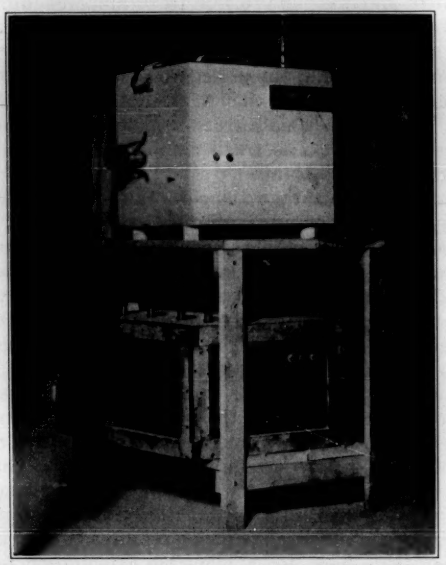
The method for measuring the activity of the polonium is illustrated in Fig. 1. The polonium plate *a* was mounted in the ionization chamber *I* with a difference of potential of 300 volts between *a* and *b* supplied by the battery *A*, while *b*, the inner part of the ionization chamber, was connected to the fiber of the single-fiber electrometer. The potential for the plates of the electrometer *PP* was obtained by using a portion of the potential maintained upon the megohm resistance *MM*. The ionization chamber was supported by the case of the electrometer and insulated from it by a hard rubber ring the cross section of which is shown at *D*. The ionization chamber was 6.5 cm. high and 5.5 cm. in diameter, and the distance between the polonium plate and plate *b* was greater than the range in air of the alpha particles. The charge accumulating on *b* was neutralized by altering the potential of the condenser *C* by known amounts by means of the battery *B* and resistance *R*, as shown in the figure. Thus throughout the readings, the fiber and *b* were always kept at the same potential as the case of the electrometer, so that the possibility of leakage was greatly reduced.

Figure 2 shows a photograph of the portable apparatus used. The box on top of the stand contained the apparatus shown in the preceding figure. It was made nearly airtight and contained drying agents. The readings of the electrometer and all of its adjustments could be made without opening the box. The longer box in the lower part of the stand contained the batteries and resistances which were also kept dry. The wires connecting the two boxes were mounted on plugs of sulphur set in the sides of the boxes to insure good insulation.

The polonium plate was prepared from old radium emanation tubes in which the emanation and products had gone over to RaD. The tubes were broken up and placed in dilute HCl. The HCl was then evaporated on a copper plate,

giving an active deposit. By measuring the absorption of the radiation emitted by the plate it was found to consist of α rays, hence the activity must be due to polonium. In fact, over a period of 140 days the radiation from pure polonium

FIG. 2.



View of the apparatus which was taken into the mine.

consisting entirely of alpha rays, will diminish to half value. It was found that while the activity of the plate prepared was due almost entirely to alpha rays, its strength remained constant to two per cent for a period of ninety days. The inference is, that the amount of Radium E which remained on the plate after evaporation of the hydrochloric acid was just sufficient to generate polonium at a rate which balanced the loss by decay. While the condition obtained was accidental

and unexpected it was not without its advantages in the present work.

RESULTS AND DISCUSSION.

The activity of the plate was measured at the top of the mine and then 1,150 feet below the surface. The ionization current produced in I varied only between the values of 9.6×10^{-11} amperes and 9.7×10^{-11} amperes during the entire course of the measurements. We thus conclude that there is no effect of cosmic radiation on the disintegration of the polonium to within one per cent. The natural ionization of the ionization chamber when at the bottom of the mine was 6×10^{-13} amperes. This current, which must be due to the activities of the rocks is small compared to the ionization produced by the polonium.

Swann [5] has shown that a single cosmic ray, by using all of its energy in ionization, is capable of producing 5.4×10^6 ions and has pointed out that since Millikan has found that cosmic rays produce 1.4 ions per cc. per sec. in air at sea level, we would have $1.4/5.4 \times 10^6$ cosmic rays absorbed per cc. per second in air or 1.3×10^{-4} cosmic rays absorbed per second per gram of absorbing material so that the 10^{-11} grams of polonium contained on the plate would absorb 1.3×10^{-15} cosmic rays per second. This would mean that a cosmic ray would be absorbed by one of the polonium atoms once in 10^{15} seconds or once in about 2×10^7 years, a situation which entirely precludes any attempt to measure the change in activity if we assume that the absorption of one cosmic ray is to be associated with the disintegration of one atom.

While the considerations which have already been involved leave very little hope for a plausible explanation of radioactivity as a result of the action of cosmic rays, it is worthwhile to consider the possibilities of a different view point with regard to the action of these rays than the particular mechanism which we have already considered. Let us then trace the results which would follow from the assumption that the ray is to be considered as of the nature of a particle, which in its passage by an atom must approach within a certain distance in order that it should produce the necessary disintegration. A simple calculation of the number of polonium atoms on the plate used will show that the total number per

sq. cm. is of the order of 1×10^{10}, and that therefore the distance between the atoms is of the order of 1×10^{-5} cm, that is about 1,000 atomic diameters. We should naturally expect that a cosmic ray operating as a corpuscular entity would have to approach nearer than this distance in order to produce a disruption of the atom. The condition is in fact one of single impact of the cosmic rays in passing through the plate and the maximum effect to be expected is one in which each cosmic ray disrupts one atom while penetrating through the plate. The problem now remains to calculate the number of cosmic rays per second which at sea level will pass through the polonium plate.

We shall assume that cosmic rays are generated in interstellar space and let $N(R)$ be the number of cosmic rays generated per unit volume per second between R and $R + dR$. Then $N(R)R^2 \sin\theta\, d\theta d\phi dR$ (spherical coördinates) will be the number of cosmic rays created per second in the polar element of volume dv in interstellar space. The distance R is measured from an element dS of a surface which incloses a volume V of air at sea level. The angle θ is measured with respect to the vertical. Then the total amount of energy falling on dS per second due to those rays originating in dv is given by

$$\frac{kdS\cos\psi}{4\pi R^2} N(R) e^{-(\mu H/\cos\theta)} R^2 \sin\theta d\theta d\phi dR,$$

where k is the energy of one cosmic ray and ψ is the angle which the normal to dS makes with R. H is the height of the earth's atmosphere if it were of uniform density throughout. We have here neglected any absorption which the rays might experience before coming into the earth's atmosphere. The amount of energy dE which will be absorbed in V will be

$$dE = \sum \frac{\mu l k dS\cos\psi}{4\pi} N(R) \sin\theta e^{-(\mu H/\cos\theta)} d\theta d\phi dR,$$

where the summation is taken with respect to all elements of surface dS over one-half of the area of the surface, i.e. over that part of the surface on which the energy is incident.

l is the distance traversed by these rays while going through V. Since the angle θ will not change appreciably during the summation we shall assume that it is constant and hence we have

$$dE = \frac{\mu k V}{4\pi} N(R) \sin \theta e^{-(\mu H/\cos\theta)} d\theta d\phi dR.$$

If we assume on the average that all of the energy of the cosmic ray goes into energy of ionization, then the number dQ of ions produced by the absorption of cosmic ray energy to amount dE is given by

$$dQ = KdE,$$

where $K = 1/Ue$, Ue being the energy necessary to ionize one ion. Thus we can obtain the following for q the total number of ions formed per second per cc. in V

$$q = \frac{\mu k K}{4\pi} \int\int\int N(R) \sin \theta e^{-(\mu H/\cos\theta)} d\theta d\phi dR. \qquad (1)$$

The integration will be taken over a portion of the region outside of the earth's atmosphere where cosmic rays are being generated, i.e. over the space for which θ varies from 0 to $\pi/2$, ϕ from 0 to 2π, and R between the values R_1 and ∞. The function $N(R)$ is assumed to become zero at infinity in such a manner that $\int_{R_1}^{\infty} N(R)dR$ will be finite.

The number of cosmic rays dn passing through ds, an element of a horizontal surface, is given by

$$dn = \frac{ds}{4\pi} \int\int\int N(R) \cos \theta \sin \theta e^{-(\mu H/\cos\theta)} d\theta d\phi dR.$$

In this equation $\cos \psi$ has been replaced by $\cos \theta$ since now ψ and θ are equal. Thus we have the following for S the number of cosmic rays per second per sq. cm penetrating through the horizontal surface.

$$S = \frac{dn}{ds} = \frac{1}{4\pi} \int\int\int N(R) \cos \theta \sin \theta e^{-(\mu H/\cos\theta)} d\theta d\phi dR.$$

From equations 1 and 2 we now have on integrating

$$S = \frac{q}{\mu k K} \frac{\int_1^\infty \frac{e^{-\mu H x}}{x^3} dx}{\int_1^\infty \frac{e^{-\mu H x}}{x^2} dx}, \quad [1]$$

where $x = \sec \theta$. kK gives the number of ions a single cosmic ray is capable of producing and is equal to 5.4×10^6 for a cosmic ray having an energy corresponding to an absorption coefficient of approximately 1×10^{-6} per cm. of air. For this value of μ we now have

$$\int_1^\infty \frac{e^{-\mu H x}}{x^2} dx = .136 \quad \text{and} \quad \int_1^\infty \frac{e^{-\mu H x}}{x^3} dx = .103,$$

where $H = 10.5$ meters for the water equivalent of the earth's atmosphere measured at sea level. q for air has been found to be 1.4. By using these values, S comes out equal to about .2 cosmic ray per sq. cm. per sec.

The area of the polonium plate used in this experiment was 10 sq. cm. and therefore two cosmic rays would pass through it per second. There were about 3,000 atoms of polonium disintegrating per second and if each cosmic ray striking the plate were capable of causing one atom to disintegrate, irrespective of the fact that it may be necessary for the cosmic ray to approach within a certain distance of the atom, then the total cosmic radiation would contribute to less than one-tenth of one per cent. of the activity of the polonium. According to these considerations we should not expect to find an effect of cosmic radiation on the rate of disintegration for the present work.

The Writer wishes to thank the New Jersey Zinc Company for the permission to carry on the experiment on their mine at Franklin, New Jersey: and desires to express his gratitude to Dr. F. C. Benson of the Hahnemann Medical College and Hospital of Philadelphia for supplying the radium emanation

[1] This expression is of the same form as that deduced by Swann for the ratio of the influx of atmospheric corpuscles per sq. cm. per sec. into the earth, to the corpuscular current absorbed per sec. per cc. by a mass of metal.

tubes used in the preparation of the polonium, and to Dr. A. Bramley for his assistance in taking the measurements at Franklin, New Jersey. The Writer also wishes gratefully to acknowledge the helpful suggestions of Professor W. F. G. Swann.

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THE REFLECTION OF HYDROGEN ATOMS FROM CRYSTALS: INTENSITY MEASUREMENTS OF THE SPECULARLY REFLECTED BEAM.

BY

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Communication No. 35.

IN a previous paper in this journal [1] some qualitative results were reported on some intensity characteristics of the specularly reflected beam of hydrogen atoms from a crystal of rock salt. These results were based chiefly upon visual comparisons of the intensities of the traces produced by the specular beam on the detecting plate which was employed for recording the reflected atoms. Since then an attempt has been made to make quantitative measurements of the intensity of the specular beam as a function of the angle of incidence and of the temperature of the crystal. Although the precision of these measurements is still rather poor and they have not been extended as far as seems desirable, yet certain definite and interesting results have been obtained and as the work is temporarily interrupted it seems advisable at this time to publish what has been done.

The apparatus and general method of the investigation were the same as reported in the earlier paper. A beam of hydrogen atoms, originating in a discharge tube and collimated by two slits, was allowed to fall upon a crystal of rock salt which could be heated to expel the adsorbed gas layer. The reflected atoms were recorded on a glass plate coated with molybdenum oxide which became darkened by reduction where the hydrogen atoms struck it. The intensity of the reflection was then quantitatively measured by making a densitometer analysis of this plate.

In order that these measurements might be relied upon as representing the true density of the reflected atom beam,

[1] JOUR. OF THE FRANK. INST., Vol. 206, p. 301.

several precautions were necessary. As in the earlier work the detecting plates were made by smoking a piece of glass over an oxygen-gas flame in which metallic molybdenum was being burned. To improve the uniformity of the oxide deposit, so that measurements of the densities over different parts of the plate might be compared, it was found of great advantage to use a chimney for the smoking operation. This consisted of a brass tube, one inch in diameter and six inches long, in the center of which were one or two wire gauze diaphragms. At the lower end, along with the smoke from the flame, a fine jet of air was introduced which produced a thorough mixing, so that with the proper adjustment of smoke and air, a dense and very uniform cloud emerged from the upper end of the chimney. A glass plate held in this cloud became coated with a very uniform deposit of about the right density in a minute or two.

The intensities of the specularly reflected atom beams at two different angles were compared by making two exposures on the same plate. More than two such exposures on the same plate were found impractical because of the resulting great intensity of the diffuse background which was always present. In order to annul any inequalities in the specular beams at the two angles arising from changes in the intensity of the primary beam, the crystal was rotated first to one position and then to the other at frequent and regular intervals. Although this precaution was taken when possible, it was not considered necessary, for with the arrangement which was used for regulating the flow of gas, the pressure in the discharge tube, after coming to equilibrium, remained constant to within what could be read on the McCleod gauge over an indefinite period.

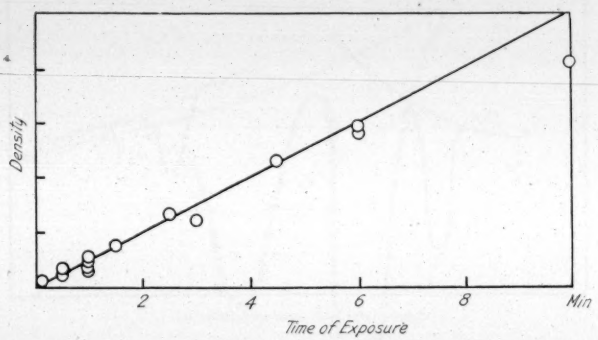
A calibration plate was taken to determine the relation between the measured density of the detecting plate and the number of atoms which had struck the plate per unit area. This plate was mounted for exposure in the apparatus in such a way that it could be moved parallel to itself and perpendicularly to the beam. It was exposed in different positions for varying times to the primary atom beam, which was of constant intensity, so that after the exposure, it was crossed with a series of dark lines of varying densities.

The plate was then analysed with a densitometer and the densities D of the exposed regions were calculated by means of the relation

$$D = \log I_0/I,$$

in which I is the intensity of the light transmitted by the densitometer through the exposed part and I_0 is the intensity of the light which would have been transmitted had the plate remained unexposed. I_0 was found by interpolating between the measurements which were made on either side of the exposed line. The results of the measurements of the

FIG. 1.

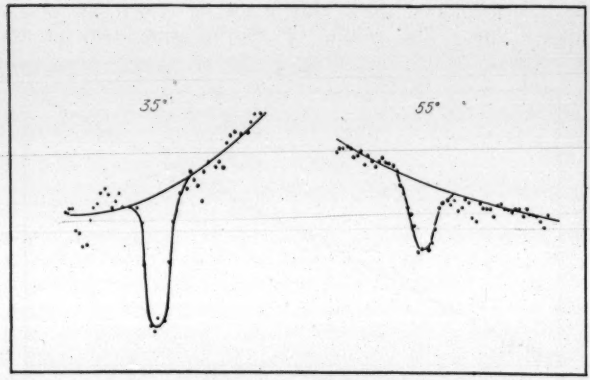


calibration plate are shown in Fig. 1 in which the densities of the centers of the exposed lines are plotted against the time of exposure. It is evident that the density is proportional to the time of the exposure, or what is the same thing, to the number of atoms per unit area, unless the plate has been over-exposed. We may therefore use the densitometer measurements for determining the relative intensities of beams if they are exposed on the same plate for equal times.

If the plate is left exposed to moist air for any length of time after exposure it again turns white by oxidation. A convenient way of avoiding this was to seal a second glass plate over the oxide coated surface. In this way some records have been kept for a year without any very noticeable fading.

To illustrate the procedure by which the actual measurements were carried out, some results of the densitometer analyses of the regions around the specularly reflected beams are shown in Figs. 2 and 3. The two beams shown in Fig. 2 were reflected for equal times onto the same plate with the crystal maintained at a constant temperature but at the angles of 35° and 55° respectively. The calculation of the

FIG. 2.

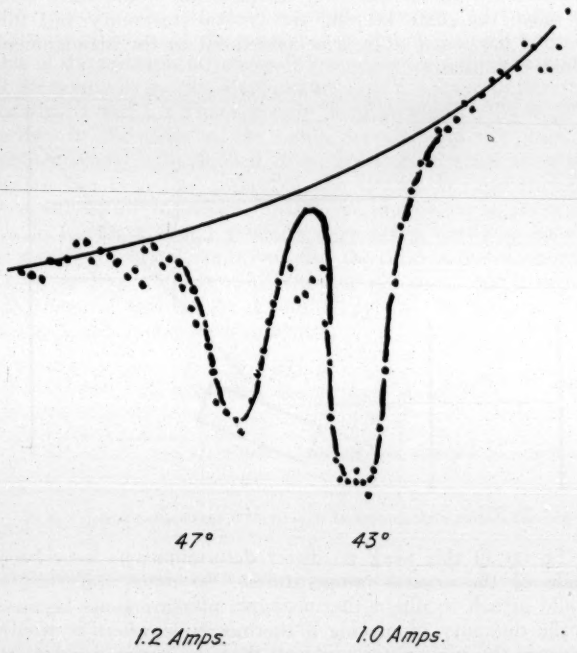


Densitometer analyses of specular beams.

beam intensities was carried out by either of two methods. With the first method the density, as defined above, was calculated for each position in the beam, using the values of I_0 found by interpolation between the measurements in the adjacent regions which were exposed to only the diffuse reflection. The calculated density was then plotted as a function of the position, and the area under the resulting curve was determined with the use of a planimeter. If the detecting plate had been circularly cylindrical with the crystal at its axis, the area of these curves would at once represent the beam intensities. The plate, however, was flat and was located with respect to the beam and crystal as shown in Fig. 4, P_1 or P_2. In the position P_1 comparisons could be made directly from the integrated density curve if

the two beams were symmetrically located with respect to the 45° position. Otherwise a correction was necessary because of the difference in the beam paths r between the detecting point and the source slit S_1. This correction is proportional to r. The intensities could also be calculated

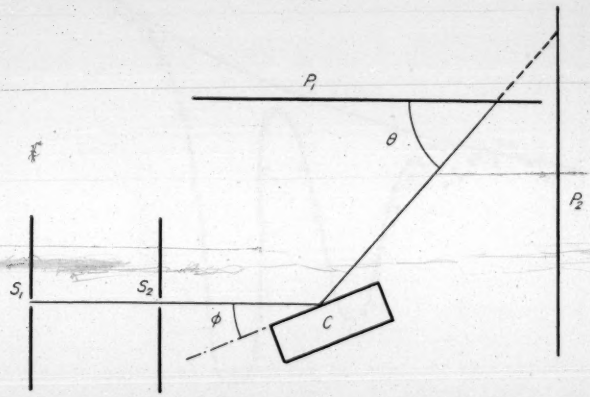
FIG. 3.



from the values of I and I_0 at the position of greatest density. To obtain the beam intensity in this case corrections had to be applied to the measured densities which were proportional to $r^2 \sec \theta$ where θ is the angle between the direction of the reflected beam and the detecting plate. Figure 3 shows the results of the densitometer analysis of a plate made for the

purpose of studying the variation of the beam intensity with temperature. In this case the crystal was rotated through only a small angle in order that the change of intensity because of the different angles might also be small. The error which was incurred from this change in angle is discussed below. A better method for determining the effect of temperature on the intensity of the beam would have been to move the plate keeping the crystal stationary, but this method happened to be less convenient in the arrangement which was used.

FIG. 4.



Schematic diagram of the arrangement of the crystal C, and the detecting plate P_1 or P_2.

So far in this work no direct determinations have been made of the crystal temperatures. So much uncertainty would attach to direct thermocouple measurements because of the difficulty of placing a thermocouple where it would measure the surface temperature that the entire problem of determining the temperature has been left for a future time. Hence the temperatures are only known in terms of the currents which were used to heat the crystal holder.

Since the contrast between the exposed and the unexposed parts of the plate is much greater by reflected than by transmitted light it was possible to notice effects visually

which were often unnoticeable from the densitometer measurements. For this reason many plates could be studied visually although they were either too weakly exposed or the oxide coating was not sufficiently uniform for accurate measurements. From a comparatively large amount of qualitative data, it is therefore possible to state that the effects shown by the quantitative data, meager though they are, are definite and reproducible. It is impossible, however, to make an accurate estimate of the reliability of the quantitative work. One of the principle errors doubtless arises from the scattering of the points in the densitometer analysis graphs as illustrated by Figs. 2 and 3. This can only be accounted for by irregularities in the glass or the oxide deposit, and not until a further study is made will it be possible to state to what degree the reflecting power of the crystal is reproducible. A summary of the more reliable measurements is given in Table I. Data 6 and 7 which were taken under as nearly as possible identical conditions give the ratio of the intensities at 55° and 35°. They differ by nine per cent., but it seems that most of this can be accounted for by the uncertainties in the densitometer measurements.

TABLE I.

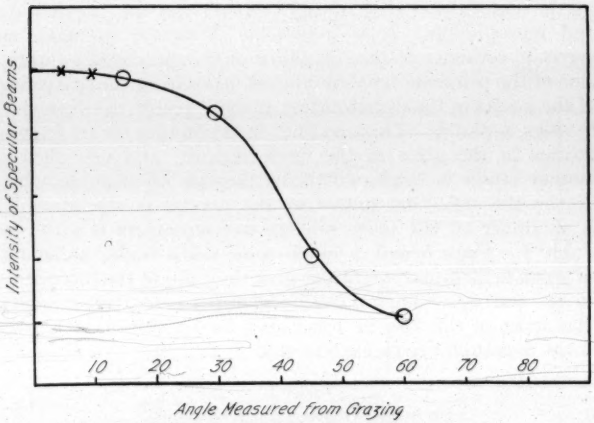
The Relative Intensities of Specular Beams.

	Angles from Grazing.		Intensity *a* : Intensity *b*.	Crystal Heating Current.
	a.	*b*.		
1	60°	30°	.26	1.4 amps
2	45°	30°	.48	" "
3	15°	30°	1.10	" "
4	5°	10°	1.00	" "
5	45°	35°	.56	1.0 "
6	55°	35°	.56	" "
7	55°	35°	.61	" "
8	55°	35°	.39	1.1 "
9	55°	35°	.38	1.3 "
10	43°	47°	1.66	1.0 " 1.2 "

The first four data are shown graphically in Fig. 5. These were all obtained from one crystal at a temperature corresponding to a heating current of 1.4 amperes. This temper-

ature was just under that at which the sublimation of the crystal began to be noticeable. Unquestionably this curve represents the general features of the intensity variation with angle, although the precision is not sufficient to make the numerical values reliable.

FIG. 5.



The variation of the intensity of the specular beams with angle.

The other data were obtained from a second crystal and bring out two other interesting points. (1) *The ratio of the intensity at an angle near normal incidence to the intensity at an angle near grazing, becomes greater as the temperature of the crystal is reduced.* (2) *The intensity of the specular beam at any particular angle is greater at low temperatures than at high temperatures.* Although the measurements upon which these statements have been based are confined to but a few angles nothing has been observed to suggest that the statements are not true generally, and in fact they are supported by several plates exposed at other angles which were examined only visually. Datum 10 upon which (2) is based must of course be corrected for the fact that the two beams were not reflected at exactly the same angle. If the variation were as great as that shown in Fig. 5 for which the temperature was

high, an intensity ratio of 1.2 could be accounted for by a change in angle of 4°. It has been shown, however, that this ratio is considerably less for temperatures corresponding to the heating current of 1.0 amperes, and we may safely conclude that the temperature effect is the important cause of the intensity difference of the two beams studied in 10.

Unfortunately the temperatures at which intensity measurements are possible, are limited to a narrow range between the point at which sublimation begins to be important, corresponding to a heating current of 1.5 amperes, and a point where a change in the crystal surface takes place. This change may probably be attributed to the formation of NaOH under the combined action of atomic hydrogen and adsorbed water vapor and it takes place at a temperature corresponding to about .6 amperes. It seems particularly desirable to establish the law of the intensity variation and the law of the variation of the angular distribution of the intensities of the specular beams as a function of the temperature, even if only over this short range, in order to determine the part played by the thermal agitation of the surface molecules. Qualitatively the variations are in the right direction to be explained by a roughening of the surface by thermal agitation, assuming the hydrogen atoms may be regarded as plane de Broglie waves. Since the average wavelength of the atoms which were used was about 1 Å and therefore of the same order as the expected amplitude of the oscillations of the surface atoms, it may be expected that a large variation of intensity such as is observed might well take place from this cause.

Determination of the Velocity of Light by Means of the Kerr Electro-optical Effect. A. KAROLUS and O. MITTELSTAEDT. (*Phys. Zeit.*, No. 19, 1928.) In Fizeau's determination of the velocity of light a ray of light passed between two teeth of a rotating wheel, proceeded over a distance of some eight kilometers to a mirror by which it was reflected so as to traverse again its previous path. Upon its arrival at the wheel it would be caught upon a tooth, provided a tooth had moved ahead and occupied exactly the position formerly held by the space between two teeth. The time taken by the light to go from the wheel to the mirror and back would then equal the time required for the tooth to occupy the position of the space. From the speed of rotation of the wheel and the distance from wheel to mirror the velocity of light can be calculated. The accuracy of the result depends upon the exactness with which these two quantities can be measured.

The method described in this paper goes back to a suggestion made by Des Coudres in 1893. The rotating wheel is replaced by a Kerr cell placed between crossed Nicol prisms. A ray of light is directed upon the first prism from which it goes to the cell and thence to the second prism. Under ordinary conditions no light can get through. If however, arrangements of direction being propitious, an alternate-potential be applied to the cell, then twice every cycle light will get through for an instant. There is thus an optical interrupter whose frequency is dependent on that of the applied potential. A second Kerr cell was used in the arrangement for receiving the light after its passage through the interrupter and across the distance separating this from the receiver. The applied frequency was measured with an error of about .02 per cent. The distance traversed by the ray of light amounted to about 332 meters all within the compass of a laboratory since the light was reflected several times by mirrors before finally reaching the receiving end. This distance was measured with an accuracy of .04 per cent. The total error thus did not exceed the sum of .02 per cent. and .04 per cent. or .06 per cent. From about 750 determinations the mean value of the velocity of light is given as 299,778 km. per sec. Michelson's result is 299,796 km./sec. By an error of arithmetic the authors give the mean error of their result as 20 km./sec. whereas it should be 180 km./sec. G. F. S.

THE REFLECTION OF HYDROGEN ATOMS FROM CRYSTALS: VELOCITY SELECTION IN THE SPECULAR BEAM.

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Communication No. 36.

In an earlier publication [1] some experiments were described in which it was found that hydrogen atoms were specularly reflected from a natural crystal surface of rock salt if the latter was maintained at a temperature just under that at which sublimation takes place. More recently the same result has been found to hold for KCl crystals and is presumably true for certain other crystals as well. At that time it was pointed out that if one is to understand this phenomenon in a way which is consistent with the roughness of the interatomic forces as assumed in the well-developed theory of crystal structure as worked out by Born and Lennard-Jones, it is necessary to think in terms of wave mechanics rather than classical mechanics. It is, of course, to be expected that a difference between the classical and the wave mechanical predictions should exist for this phenomenon since the wave-lengths ($\lambda = h/mv$) associated with hydrogen atoms of the velocities used are of the order of the distances between the atoms of the crystal. It was further pointed out in the earlier paper that, although diffraction beams from the surface of the crystal lattice of higher order than the zeroth (specular beam) would be expected to appear if atoms of homogeneous velocity could be used, yet in the beam which is available the Maxwellian velocity distribution covers such a wide range that even the first order beam would be a band distributed through at least 50°.

In addition to the elastically reflected atoms which should be found in these diffraction beams there is also a very large number of inelastically reflected atoms which are distributed

[1] JOUR. OF THE FRANK. INST., Vol. 206, p. 301.

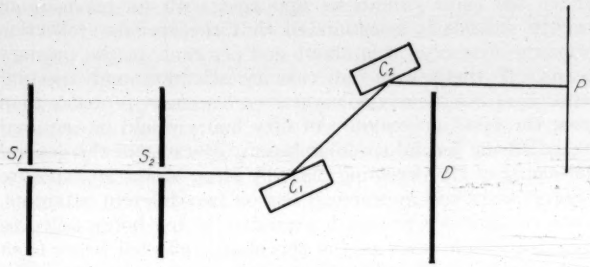
in all directions in about the ratios of the cosines of the angles from the normal to the crystal surface. For this reason only a relatively small number of the atoms reflected at any angle outside the specular beam may be expected to have undergone diffraction so that until a beam of homogeneous velocities is used it will doubtless be impossible to demonstrate the existence of diffraction from the surface lattice. In the direction of specular reflection, however, the number of elastically reflected atoms is a very considerable part of the total. Therefore it seems that whatever evidence is to be gained with the use of inhomogeneous beams, pertaining to the problem of elastic reflection, must be obtained from measurements made upon the specular beam itself.

In the investigation about to be described some evidence has been obtained concerning the velocity selection in the specularly reflected beam. A particular interest attaches to this work in the light of a recent publication by Ellett and Olson. These investigators have found that a beam of cadmium atoms, specularly reflected from a crystal of rock salt, is of homogeneous velocity, selected according to the angle in a manner analogous with Bragg interference of X-rays. Their results were quite unexpected for two reasons. In the first place the resolving power of the crystal in the experiments of Davisson and Germer has shown that even electrons penetrate the crystal to a depth of only a few atoms, and it would be expected that cadmium atoms could penetrate much less deeply, if at all, and still undergo elastic reflection. In the second place, the wave-length which they have measured is that given by $\lambda = h/m_H v$, where m_H is the mass of one proton and not that of the cadmium atom. As these authors have themselves pointed out, this result is quite inconsistent with the wave mechanical expectations.

In order to test whether or not a beam of hydrogen atoms which has been specularly reflected from a crystal of rock salt is of homogeneous velocity, this beam was again reflected from a second crystal at the same angle. If the first specularly reflected beam contains only atoms with certain selected velocities it should be reflected from the second crystal with greater intensity than a beam containing the same number of atoms distributed according to the Maxwellian law.

A schematic diagram of the experimental arrangement is shown in Fig. 1. Atomic hydrogen, formed in a discharge tube, by the dissociation of molecular hydrogen was collimated into a beam by means of two slits, S_1 and S_2, between which the excess gas was eliminated by a high speed diffusion pump. The beam thus formed was reflected successively from the two crystals C_1 and C_2 and thence it fell upon the molybdenum oxide coated detecting plate P. The technical details were in most respects the same as were described

FIG. 1.



more fully in the earlier paper. Both crystals were mounted on compound eccentric ground glass cones which permitted adjustment both as regards position and inclination. The actual adjustments were made optically and the reflecting angle could, by this method, be made accurately the same for both crystals to well within the angular width of the beam (about 1°). The diaphragm D protected the region on the detecting plate, where the specular beam was expected, from diffuse atoms from the higher pressure region between the two collimating slits as well as from the diffusely reflected atoms from the first crystal. This precaution made it possible to run an exposure for ten hours with no more general darkening than was usually obtained in one hour without the diaphragm. The general darkening which eventually covered the plate and limited the exposure to about ten hours was due to the incomplete effectiveness of the surrounding walls in catalysing the recombination of the stray hydrogen atoms, in spite of the fact that these walls were coated with

platinum black and protected from grease and wax vapor by the guard rings described in the earlier paper.

Before making a long exposure to detect the reflection from the two crystals in succession, each crystal was first tried alone. Since no appreciable variation has ever been found to take place in the reflecting power of a crystal because of exposure to the air, these tests could be made separately and before the final plate was inserted. A visible trace of the specular beam from a single crystal appeared after an exposure of about one-half hour. Since the primary beam under the same conditions appeared with an exposure of twenty seconds it is estimated that the specular reflection from the first crystal is about one per cent. of the primary beam. If there were no velocity selection and specular reflection from the second crystal were no more probable than from the first, an exposure of fifty hours would be required to record the second specular beam. Because of the general darkening of the detecting plate by stray atoms an exposure of fifty hours was impractical but on two different attempts, when conditions were good, exposures of ten hours failed to record a visible trace of the specularly reflected beam from the second crystal. These exposures were made at angles close to 20° from grazing.

It is concluded, as a result of this experiment, that the velocity selection in the specular beam is less than enough to increase the probability of specular reflection from the second crystal by more than a factor of five. This result may be stated more precisely as follows. If $N(V)dV$ is the number of atoms in the primary beam with velocity between V and $V + dV$, and $P(V)$ is the probability that one of these be specularly reflected, then the experiment shows that

$$\frac{\int_0^\infty N(V)P^2(V)dV}{\int_0^\infty N(V)P(V)dV} < \frac{1}{20}, \tag{1}$$

whereas it is known that

$$\frac{\int_0^\infty N(V)P(V)dV}{\int_0^\infty N(V)dV} = \frac{1}{100}. \tag{2}$$

If P were independent of the velocity equation (2) would yield the value 1/100 for P and the value of the left side of (1) would then be equal to 1/100. On the other hand, if complete velocity selection occurred so that P were unity for certain values of V and zero for all others, the left side of (1) would be equal to unity. The fact that it is less than 1/20 and therefore quite small, expresses the fact that P is nearly independent of V and there is little, if any, velocity selection.

This result agrees with an experiment which was reported in the earlier paper in which it was found that an interference phenomenon of the Bragg type depending upon the lattice spacing of the rock salt crystal and wave-length $\lambda = h/mv$ for the hydrogen atom, was ineffective in determining the probability that an atom be specularly reflected. The result is, however, at variance with that found by Ellett and Olson for cadmium atoms, but, since the mass of a cadmium atom is 112 times that of the hydrogen atom and its deBroglie wave-length is one-tenth that of the latter, it is perhaps not surprising that differences should exist even though the reason for these differences is not known.

Demonstration of the Doppler Effect in Sound. J. ZENNECK. (*Phys. Zeit.*, No. 11, 1928.) A loud speaker is attached to a flat piece of iron and the whole is swung from the ceiling of the lecture room by a bifilar suspension. An alternating current of frequency 1,000 per sec. is sent through the loud speaker while it swings back and forth in a plane perpendicular to a wall nearby. A person in the audience receives two sound waves, one direct from the loud speaker, the other by reflection from the wall. When the apparatus swings toward the auditor he gets from it a note whose pitch is higher than when it is at rest, while at the same time the note he gets by reflection from the wall is lowered in pitch because the acoustical image of the loud speaker is receding from him. He therefore hears beats. These are fastest when the pendulum is at its lowest point for there its velocity is greatest. The frequency of the beats can be changed through a wide range by changing the amplitude of the swing. G. F. S.

Up to the year 1925 helium was liquefied only in the cryogenic laboratories situated in Leyden and in Toronto. In that year a third apparatus for the same purpose was installed in the Physikalisch-Technische Reichsanstalt. In 1927 a new building for the production of low temperatures was erected in connection with the institution. 20 liters of liquid nitrogen per hour and 10 liters of liquid hydrogen per hour can be produced.

The helium gas for liquefaction is derived either from a mixture of neon and helium furnished by the Linde Company or from crude helium coming from the Auer Co. and obtained from monazite sand. From the first of these sources only about 70 liters of pure helium are produced per day. To get this 7 l. of liquid hydrogen must be used. The yield per day of helium gas from the second source of supply is 500 liters and again 7 l. of liquid hydrogen are employed. The stock of helium gas kept on hand amounts to about 6 cu.m. In 9 minutes from the appearance of liquid helium 400 cu.cm. are collected. G. F. S.

THE DEVELOPMENT OF A FIVE-STRINGED CELLO.*

BY

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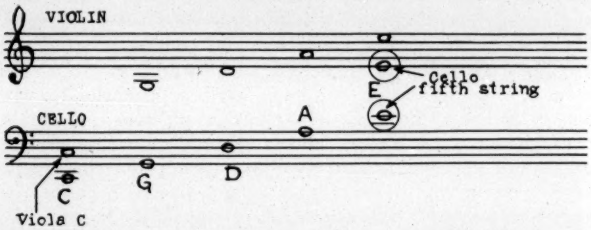
The usual cello has four strings tuned as shown in Fig. 1. For comparison, the four open strings of the violin are also indicated. By "stopping" or pressing a string down against the fingerboard any intermediate note may be obtained. On the ordinary cello, the range one octave above the open A is obtained with comparative ease, after a few years of

FIG. 1.

The open strings on the violin, viola, and cello, showing the added fifth string.

practice. Above that note, there still is a useful range of at least two octaves, but these notes are not only more difficult to produce and to play in tune, but the tone quality becomes nasal and the volume decreases as the string is shortened. Generally speaking, the same limitation applies to the upper range of the violin, with the following differences: (*a*) The whole range of the violin is the useful "solo" range, whereas in the cello the pitch of the lower two strings is too low for a melody and these strings are mostly used in ensemble playing, for the bass part and the accompaniment. Even the D-string of the cello is somewhat low for solo playing, because the

* The substance of this article was presented by the author in a talk before the Franklin Institute on December 6, 1928, at which time the instrument itself was demonstrated.

piano accompaniment has to lie above it. Thus, the A-string on the cello is the only one preëminently used in solo playing, and the range of one octave is not sufficient for anything but a very simple melody. (*b*) The fraction of the length of a string above which playing is practically impossible is a function of the string diameter. The thinner the string the farther it may be stopped without producing unpleasant partials. Thus, on the violin higher notes are more pleasant and are easier to produce than the notes corresponding to the same fraction of the length on the cello.

In other words, the range of the ordinary cello as a solo instrument is insufficient without going to high positions which are difficult to play and on which the tone quality is not nearly on par with that of the lower positions. Yet composers continue to write works for the cello using unreasonably high notes, for the same reasons for which they write songs just above the comfortable range of the singers. The reasons given are, first, that the composer could not possibly express his ideas keeping within the best range, and secondly that his music has been written primarily for the best performers who know how to overcome tone difficulties. Even in orchestral playing, and in chamber music, where the violas and the violins are available, one often finds cello parts written on quite a high range, partly because the composer wanted a cello tone quality and partly because the other instruments have other parts to carry. Whatever the reasons for writing unreasonably high music for the cello, the situation which actually confronts a performing cellist is that the best cello music is to a considerable extent written on high positions. No wonder that since the days of Johann Sebastian Bach (1685–1750) cellists and cello makers have been interested in adding a fifth string, to extend the range of the instrument upward without resorting to high positions.

Bach's biographer, Spitta, gives rather meager information about Bach's five-stringed cello. We know that it had an E-string (Fig. 1) one-fifth above the open A, and that it was called "viola pomposa" and "cello piccolo." Some of these instruments apparently were intended to be played resting on the floor with a pin, like the present day cello (Fig. 2), whereas others were supposed to be held against the chin,

FIG. 2.

Prof. Vladimir Karapetoff with his five-stringed cello.

like the violin. Bach also wrote a Suite (No. 6) for a five-stringed cello. It may be of interest to note that one of these early instruments, supposed to be made for Bach, is now in Philadelphia, a cherished possession of Mr. Ben Stad. Of course, the fifth string is gone, and we have no idea of the material of which it was made.

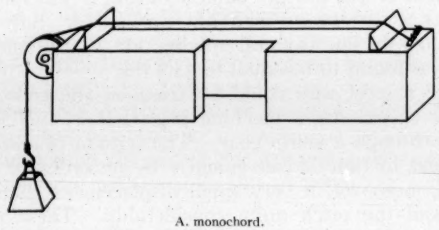
While Bach's instrument was not a success, there are somewhat indefinite records of later cellists having tried to attach a fifth string to their cellos, but without success. Yet, most any advanced performer would welcome such an instrument if he were presented with one, fully developed and ready to perform upon. The difficulties encountered in the construction of the earlier instruments will become clear from the following account of the development work done by the writer of this article.

I became interested in the five-stringed cello about 1913, for the same reason as my predecessors, that is, to be able to play advanced and more interesting cello pieces without using high positions. Not knowing anything about the physical difficulties, I simply removed the A-string, procured a triple length of the violin E-string and tried to tighten it up to the pitch of E (Fig. 1). It broke long before it came up to the pitch. I tried the best violin strings I could obtain, of different thickness, I had special gut and silk strings made for me by one of the leading manufacturers of strings, to possess the greatest tensile strength they knew how to obtain. All these strings broke either before being fully tightened or shortly afterward. I also tried a fine steel wire, but it also broke before coming up to the pitch.

Then I decided to investigate the subject scientifically, and either to solve the problem or to find the reason for which it could not be solved. I took a monochord (Fig. 3) and placed its two bridges at the same distance as the vibrating length of a cello string (about 27.5 inches). Then I fastened an ordinary cello D-string in the manner shown and loaded the free end with weights until the string came up to its required pitch of D. The necessary tension was about 20 lbs. Then I fastened an ordinary gut A-string and found that it

took about 28 lbs. to keep it at the required tension corresponding to the pitch of A. After that, I turned my attention to steel wire as the only one that looked promising for the E-string. The kind of wire with which I experimented and which I now use for the E-string and for the A-string is steel

FIG. 3.



A. monochord.

wire which one can obtain in music stores, wound on small wooden spools. It is used in some plucked stringed instruments and is drawn to the Webster and Horsefall gage, which is as follows:

Gage number	0	1	2	3	4	5	6	7	8
Diameter in mils	9	10	11	12	13	14	16	18	20

I began with a wire of No. 1 gage and found that it could be easily stretched to respond to the pitch of E, but the tone was poor. Then I tried wires of larger diameter and determined that a No. 5 wire required about 35 lbs. I did not dare to subject the cello to a greater tension and did not try wires of larger diameter. The then incomprehensible part of the experiment was that on the monochord all these wires could be tightened considerably beyond the pitch of E without breaking, whereas in the cello a No. 1 wire broke before reaching the pitch of E.

Before going any further, I checked the observed value of tension for No. 5 wire with the familiar formula for the number of double vibrations for a string per second. Namely

$$N = [1/(2L)]\sqrt{Pg/w} \qquad (1)$$

In this formula, L is the length of the string between the

bridges, in inches; P is the longitudinal tension in lbs.; $g = 386$ in./sec.^{2} is the acceleration due to gravity, and w is the weight of the wire, in lbs. per inch of its length. Assuming the middle C to correspond to 256 vibrations per sec., the E, a major third above it, is of the pitch $N = (5/4)256 = 320$ vib. per sec. The weight of the wire was computed on the basis of 484 lbs. per cubic foot and it was found that $w = 0.431 \times 10^{-4}$ lbs. per inch; $2L = 55$ inches. Substituting these values in eq. (1) and solving for P, the theoretical tension was found to be equal to 34.5 lbs.

Before a steel wire could be tried on the cello, it was necessary to provide a machine peg, that is, one which is operated through a worm gear. The tension of a steel wire is too great to tune it conveniently by an ordinary wooden peg, and, moreover, a very small displacement changes the tension and the pitch quite considerably. These machine pegs are similar to those used on a doublebass, only smaller. The machine peg for the E-string worked so well that ultimately all five pegs were changed to the worm-gear type (Fig. 2). When a steel wire was first tried on the cello, the wire broke again and again before coming up to the pitch, no matter how carefully it was tightened. Since it did not break on the monochord, and since it usually broke at the peg, the evident conclusion was that there were large secondary stresses at the peg which were added to the main tension. A close observation showed that a steel wire under tension twisted considerably when wound on a peg.

To remedy this, the wooden body of the peg was replaced by a brass cylinder, and the end of the string was fastened as carefully as possible, to minimize the secondary stresses. At the present time, the E-string breaks perhaps once in two years, and even then the break is not at the peg and is usually due to rusting. Within the last few years a heavier wire, No. 6, has been used, because it gives a greater volume of tone. The tension is probably about 45 lbs.

Before all the five strings could be used, it was necessary to raise the bridge, in order to provide a sufficient clearance for the bow past the waist of the instrument (the C-holes). Anyone familiar with a bowed stringed instrument will realize that the bridge must have a certain curvature on top in

order that each string may be bowed independently, without touching the adjacent ones. With five strings and the same curvature, the bridge has to be wider and somewhat higher. The fingerboard had to be raised accordingly, by gluing a maple wedge between it and the neck of the instrument. The steel wire is liable to deepen the groove in the bridge, and it is advisable to place a small piece of leather under the wire, so as to distribute the pressure.

It was not feasible to attach the lower end of the E-string to the tail-piece, because of a too great one-sided tension, and for this reason the string was fastened directly to the tail pin. Some skill is necessary to make a proper fastening which will not pull out as the string is tightened. It is necessary to wind the end of the string several times around itself, back and forth, and finally to pinch the end against the ebony edge.

With the foregoing changes, it became possible to try the instrument, using the ordinary four strings and a steel fifth string. The fingerboard was not widened, but the outer strings were placed nearer the edges, giving a little more room. After several years of playing on the five-stringed instrument, the writer does not consider it essential to have a wider fingerboard, although a wider one and a wider neck could be easily provided, if desired. The first trials showed that the instrument was mechanically sound, but from the musical point of view it left much to be desired. Not only the tone of the new string was too metallic, but the redistribution of the stresses in the body of the instrument took away much of the sonority of the other strings. Besides, the break in the tone quality between the metal E and the gut A was too great for satisfactory connected passages on the two, and it was decided to try a steel A. There was no question of ultimate strength, as with the E-string, the stresses being much lower. It was simply the question of using a wire that was heavy enough to give the desired volume of tone. So far, wire No. 7 has been found satisfactory for the purpose.

Having thus done away with the break in the tone quality between the two upper strings, the next step was to remedy the break between the steel A and the gut D-string. Since

the steel A is just barely tight enough for proper bowing, it was out of the question to use a steel D. It would be too flabby, no matter what size wire might be chosen. To see this point clearly from formula (1), divide the numerator and the denominator under the radical, by the cross-section of the wire. The result is

$$N = [1/(2L)]\sqrt{P'g/w'}, \qquad (2)$$

where P' is the unit stress and w' is the weight per unit length and per unit cross-section, in other words, the specific weight of the material. With the pitch N, the length L, and the material constant w' given, P' becomes a definite quantity, no matter what the cross-section is. Increasing the cross-section merely increases the total tension P and also the volume of the tone, but "flabbiness" will remain. An inspection of the formula indicates that in order to increase P' and thus make the string stiffer and more convenient for bowing, it is necessary to increase w' accordingly.

Thus, the problem became one of finding a material heavier than steel and capable of standing the required unit stress P'. The only two materials which suggested themselves were hard-drawn brass and hard-drawn tungsten. The latter proved to be unsuitable partly because its w' is too great for the purpose and partly because it cannot be wound and unwound on a peg many times without breaking. In other words, while its tensile strength is quite high, it becomes readily fatigued in bending and twisting. This shortcoming was later remedied by providing steel jaws connected to steel wires, so that the tungsten wire was used only on the straight portion, a little above the upper nut and a little below the bridge. However, the tone quality proved to be somewhat harsh, and the tungsten wire was laid aside.

Hard-drawn brass proved to be a fairly satisfactory material for the D-string, especially for sustained notes where some flabbiness was not noticeable after the first attack. However, the difference between the specific weights of brass and steel is not sufficient to give the string the required tension. This was particularly noticeable in spiccato passages (springing bow) in which the string gave a noticeable twang.

The first remedy sought was to wind a brass string with some metal, such as silver, to increase its *w*. Such metal strings wound with another metal are used in the guitar and in the piano. A manufacturer of strings wound my brass string with silver strip according to my specifications, but the very first trial showed that such a string was suitable only for being plucked or struck with a hammer, but not bowed. It gave a harsh uneven sound. It was then decided to gold-plate the brass string so as to increase its *w* by about 20 per cent. and thereby to increase the tension in the same ratio. This solution proved to be entirely satisfactory, and at the present time a hard-drawn brass wire is used, of about 23 mil diameter, coated with gold about one and a half mil thick. Such a wire can be obtained from the jewelry trade. By using more gold, the string can be made tighter and probably more sonorous, although even the present string is more sonorous and mellow than the usual gut D-string.

Some difficulty was experienced in bowing metal strings, on account of their being smooth. The bow was therefore re-haired with coarser horse-hair, such as is used in double-bass bows. A more viscous rosin than the kind ordinarily used for cello bows also helped to remedy the trouble.

The tone quality proved to be quite uniform, without any break, from the lowest C to the highest notes on the E-string, over a range of nearly five octaves, except for the open E and the open A, where the tone was somewhat metallic. True, the tone quality of the upper open strings of any violin or cello differs from that of the same strings when stopped, and a skilled player carefully avoids open strings, except for special effects. Nevertheless, the metallic quality was too pronounced, and a piece of leather on the bridge did not damp it out sufficiently. A simple remedy was finally found in tying an ordinary rubber band across these two strings, about 3/4 inch below the upper nut. This rubber band may be seen in Fig. 2, just above the player's left hand. It is not tight enough to affect the pitch and yet it causes an open string to give about the same mellow tone as when stopped with a finger.

It would hardly be of sufficient interest to enumerate here various other small changes tried and abandoned, or adopted,

in order to improve the tone quality. Moreover, it was not always possible to tell whether an improvement was due to a change or to a gradual adjustment of the instrument itself to the new stresses, to a shift in the position of the sound post, etc. In some respects, even an old cello, when provided with a fifth string, behaves like a "green" instrument, and it takes time and patience to adjust it and to practice on it to limber it up. Many a time, during the last ten years, the achievement of the goal seemed almost hopeless, in so far as the tone quality was concerned, and then a noticeable improvement would unexpectedly come within a few days. The instrument is not finished yet in the sense that its tone quality is still improving, and various suggestions occur from time to time which help to release more tone.

Almost simultaneously with the writer and quite independently of him, a violin maker by the name of Perin, in Rushville, Indiana, constructed a few five-stringed cellos. A description of the present writer's instrument was published in the *Violinist* for February 1922, and the Perin cello was described by him in the April issue. We both were surprised to find that we followed similar paths unknown to each other. Perin built special bodies, larger than the usual cello, although he kept the length of the strings about the same, that is, 27 inches. In his letter to the writer, dated December 15, 1928, he makes the following statements:

"Lack of time for experimenting has prevented us from further work in developing this instrument. Also the attitude of cello teachers toward the invention has been such that we have concluded there is no call for an easier method of playing the instrument.

"We placed a small number of these instruments in different parts of the country, only a few of the users mentioning the use for which they desired them, school, concert, business (dancing), novelty (the latest thing), covering all statements. We answered inquiries from China, Africa, Australia, Canada, Japan, Austria, Brazil, in fact, almost the whole world.

"(*a*) We use a specially processed silk string and also harp wire in various sizes, smaller and larger than 26 B and S as required by the particular instrument. (*b*) Our calculations

showed more latitude for adjustment with a slightly larger body. (*c*) Noticing the apparent tension required to bring different instruments to pitch we worked to secure an apparent low tension and with our calculations for the size of body we got tension that will allow us to use gut (occasionally), silk (in the majority of cases) and, of course, steel in the remainder.

"We cannot scientifically explain some of the conditions we have experienced in our work, and can only take advantage of them as experience has taught us."

Not having seen or heard any of the Perin instruments, the writer merely records these statements as coming from a fellow-worker in the same field.

Coming now to the purely musical significance of the five-stringed cello, its importance for an individual musician depends entirely upon his aims and point of view. That which may be of primary importance to one cellist, may be of no interest to another. The following situations are typical:

(*a*) A professional or amateur cellist of limited skill and with limited time for practicing usually has a comparatively small repertoire of pieces, mostly those written on the first four positions. At least half of these are transcriptions of works originally written for other instruments or for the voice. We shall assume that he can play them adequately, even at a small concert, before not too critical an audience, which enjoys the singing tone of the cello and simple melodious pieces. There are a number of more interesting and musically more significant pieces, many of which were written especially for the cello, and which in a few places require medium-high positions with the use of the thumb. Our player may play these pieces adequately in all but these few places, but even one place played inadequately bars him from including these pieces in his repertoire. With the fifth string, all these pieces will come within the range of the first four or five positions and can be readily played by our musician. This type of player is quite common throughout the world, and to him the fifth string will mean all the difference between being and not being a solo performer.

(*b*) Many a professional or an amateur cellist can play a few thumb positions creditably, say, up to the open violin E (Fig. 1) but feels the limitations of the nasal tone quality on the high positions, and also aspires to more difficult cello pieces of the concert caliber. To him, after a few months of practice, the fifth string will prove to be a source of great enjoyment in enabling him to play his former pieces with much more facility and sonority, and also opening up a new repertoire of advanced pieces. Of course, the fifth string primarily helps the left hand, but because of easier tone production and lighter bowing, the right hand is also materially assisted when playing at the point of the bow or executing staccato and spiccato.

(*c*) A professional player of the highest caliber, who travels and gives solo recitals, can add materially to his prominence and message by using the fifth string and avoiding much playing on the highest positions, which is often of acrobatic nature and not in keeping with the natural dignity of the instrument. Anyone who will take the trouble of looking over the concert repertoire of half a dozen prominent cellists, say for the last ten years, cannot help but be impressed by the paucity of the material used, not because the cello literature does not offer sufficient variety, but because comparatively few pieces are "effective" and sound well on high positions. This applies particularly to cello concertos with the orchestra accompaniment: the volume of cello sound on high positions is totally inadequate, and the orchestra usually drowns much of the soloist's work. A steel E can be made to "cut through" the accompaniment so that the melody will come out clear and rich. This has been demonstrated by the writer on such well known compositions as the Saint-Saens Concerto, op. 33, Boellmann's Symphonic Variations, etc.

(*d*) The possibility of playing much of violin music on the five-stringed cello is a great advantage which can be enjoyed by all classes of cellists, from a beginner to the greatest virtuoso. In fact, since having added the fifth string, the writer finds that about ninety per cent. of his repertoire consists of regular violin pieces. The reason for this may be clearly seen from Fig. 1. The usual cello is more than an

octave and a half below the violin. Therefore, it is not practical to transpose violin pieces an octave lower. They would still lie on much higher positions than on the violin. On the other hand, the four upper strings on the new cello are exactly an octave below those of the violin, so that when playing them an octave lower most of the original positions are preserved, except where cello distances are beyond the reach of the human hand. This does not mean that it is necessary to re-write every violin piece which it is desired to play on the five-stringed cello. The performer simply reads from the original violin score and imagines himself playing the violin. It is only necessary to remember the corresponding positions. This can be readily accomplished after a few weeks of practice, and the results are certainly worth the trouble. The violin literature is many times more extensive and interesting than the cello literature, for the reason previously mentioned, namely that the solo range of the ordinary cello is too narrow for many of composers' ideas. Compare, for example, Bach's Suites or Beethoven's Sonatas for the violin with those for the cello, and the difference will be fully apparent.

When a violin piece has a part which lies mainly on its two lower strings, it may be played as written, without transposing, and then the next part played an octave lower. Actual experience has shown that this procedure can be effectively used in many cases. Thus, the cellist of the future can make his recital programs partly of cello pieces and partly of violin pieces, in this manner making his concerts more interesting and varied. A few changes here and there may be necessary, for example, in large chords, but as a rule the writer has found violin pieces even of concert character quite playable on the five-stringed cello.

(*e*) In chamber music, especially by modern composers, the fifth string has proved to be very valuable in making difficult parts comparatively easy. In an ensemble each note must be exactly in tune, and this makes higher positions on the cello doubly difficult and undesirable for this particular purpose. Even in some of Beethoven's chamber music unreasonably high positions are used in the cello part, and the fifth string not only permits of a better execution but also

brings out those solo passages more effectively. Of course, the player has to reduce the sonority of the strings in some places by bowing lightly.

(*f*) Composers will find new inspiration in the five-stringed instrument, in that it will do away with some important limitations of the regular cello with respect to higher positions and narrow range. There are pieces, as for example Bach's celebrated Chaconne, which should be played on the cello rather than on the violin, so as to give more depth to the lofty and somber moods. With the range limitations removed, composers should feel inclined to express their inspiration of this sort on the cello. The same applies to sonatas and concertos of which there are not nearly enough for the cello. Sonatas by Grieg, Locatelli, and others, with high positions, sound immeasurably better with the fifth string, and the performer does not have to worry about being drowned by an over-ambitious accompanist.

(*g*) No string ensemble is complete without one or two violas. The range of the viola is shown in Fig. 1, the lowest string being a C, an octave above the cello C and one-fifth below the violin G. The remaining three upper strings of the viola are the same as the three lower strings on the violin. In other words, the viola is an octave above the ordinary cello and one-fifth below the violin. Outside large musical centers it is comparatively difficult to find satisfactory viola players, because most violinists do not care to learn the alto clef and some new positions. Besides, they claim that using the viola affects their violin playing unfavorably. Many viola parts in trios, quartets, quintets, and orchestral pieces can be played on the five-stringed cello without much difficulty. The player simply has to learn to read the alto clef. No separate instrument is necessary and there can be no interference with his regular cello technique because the performer is playing his regular instrument and is using the same positions. A cellist has to know the treble clef, the tenor clef, and the bass clef anyway. It should not be much trouble for him to learn to read a fourth clef, especially since it is not much different from the tenor clef. The writer has played viola parts on his cello on many occasions, and while he forgets the alto clef in between, it comes back to him

within a day or two of practicing. Thus, the new cello will permit a further development of orchestral and chamber music playing in smaller musical centers.

Note: During the talk, the following pieces were performed by the lecturer:

Bach: Suite for the five-stringed cello (unaccompanied).
Massenet: Meditation from the opera "Thais."
Romberg: Andante from the Second Concerto.
Mendelssohn: Andante from the E-minor Concerto for the violin.
deBeriot: Scene de Ballet, for the violin.

Evidence Obtained by X-Ray Analysis of Films of Iron in Magnetic Fields as to the Ultimate Nature of Magnetism. T. D. YENSEN. (*Phys. Rev.*, July, 1928.) K. T. Compton and Trousdale examined the X-ray pattern obtained with single crystals of hematite and magnetite and found that the application of a magnetic field to the crystals made no difference in the patterns. Later A. H. Compton and Rognley studied the intensity of an X-ray reflected from the surface of a magnetite crystal and found that magnetizing the reflector made practically no difference in the intensity of the reflected ray. The joint conclusion from these experiments is that the ultimate magnetic particle is not the atom because an orientation of the atoms by the field would have been revealed by some change in the X-ray pattern. It must be something smaller than the atom. "These conclusions, however, do not preclude the possibility that in metallic substances like iron, there may be minute crystal aggregates whose orientation is affected by the magnetic field and which consequently may cause dissipation of energy and otherwise influence the magnetic properties." This paper reports an investigation made to detect the presence of such crystals that change their position when a magnetic field is produced. "Based on the results obtained, the answer must be a negative one. Even with the minutest crystals of submicroscopic dimensions, such as exist between the main crystals of iron, the evidence indicates no change in the random orientation, even when a magnetic force sufficient to produce magnetic saturation is applied. The results therefore incidentally confirm the hypothesis that the ultimate magnetic particle is an intra-atomic unit."

G. F. S.

THE HORIZONTAL RAINBOW.

BY

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VARIOUS observers have reported seeing a rainbow on a calm surface of water, often following a fog, and two, at least, have even seen rainbow clusters on calm lake surfaces. C. Juday,[1] who also cites earlier observations by others, saw the primary bow with two of its supernumeraries, and also the secondary, on Lake Mendota, Wisconsin, October 23, 1914. The other, Dr. E. D. Ball, observed on Lake Monroe, Florida, in the spring of 1928, and following a fog, three bows well separated from each other. These appear to have been the primary bow, the secondary bow, and the reflected primary, that is, the light or colors of a primary bow that left the droplets in such direction as to be reflected by the lake surface to the eye of the observer. Dr. Ball did not publish his observations, but gave them to me with the kind permission to do with them what I liked. They describe an unusual rainbow complex, and are the occasion of this note.

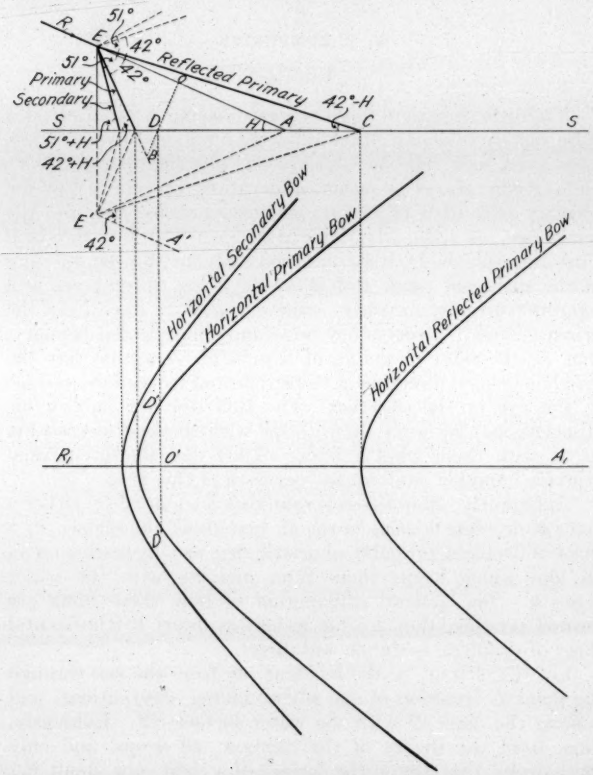
Apparently, all horizontal rainbows are caused by either a layer of droplets floating in the air just above the surface, or a sheet of droplets, probably of drizzle size, usually resting on an oil film which keeps them from merging with the water beneath. The general explanation of how these bows are formed, provided they are due, as here assumed, to a horizontal sheet of droplets, is simple and direct.

Let *RA*, Fig. 1, be the incident ray from the sun through the point *E* (position of eye when making observations) and making the angle *H* with the water surface *SS*. Evidently, then, from the theory of the rainbow, all drops, and only those drops, that are on the surface of a right cone about *RA* as axis, and having an angular spread (axis to element) at the vertex *E* of 42°, or thereabouts, as determined by color, will

[1] *Monthly Weather Review*, 44, p. 65, 1916.

contribute to the light of the primary rainbow seen from *E*. In the present case these drops evidently are at the intersection of the given cone with the plane *SS*, and therefore

FIG. 1.



along a conic section—a circle when the sun is in the zenith; an ellipse when the solar altitude is greater than 42° and less than 90°; a parabola when the altitude of the sun is exactly 42°

(of course for the appropriate color); and an hyperbola when this altitude is less than 42°.

Exactly the same things hold for the secondary rainbow seen from E on merely substituting its angular spread for that of the primary, that is, 51° in place of 42°. Similarly, the supernumeraries are just inside the primary, and outside the secondary, respectively, each with its appropriate angular distance from the axis RA, and forming on the water surface its particular curve, in the same manner exactly as does the primary bow, explained above.

Obviously an eye at E may receive not only that rainbow (primary, secondary and supernumerary) light which comes directly from the drops, but also such light after reflection from the water surface. The condition that this reflected light shall reach the point E is that it must leave the drops in the direction of E', the image below the water surface of E above it. The reflected primary bow, therefore, lies along the intersection of the water surface with a right cone of 42° angular spread, with vertex at E', and axis $E'A'$ parallel to REA. Similarly, the reflected secondary is along the intersection of the water surface with a right cone having the same vertex and axis, that is, E' and $E'A'$, respectively, with a spread of 51°; and the reflected supernumeraries just inside the reflected primary and outside the reflected secondary, respectively. It is not certain, however, that the reflected secondary has ever been observed, hence its theoretical position is not shown in the Figure. The reflected supernumeraries surely are too faint to be seen.

Furthermore, there also may be reflection bows, that is, bows produced by light reflected from the water surface into the drops, and passed from them to the observer, either directly or after reflection. Evidently the light that produces these reflection bows enters the drops in the direction of, or parallel to, $E'A$, and forms primary and secondary bows exactly like those described above due to the original, or non-reflected, incident light. Clearly, too, these bows, since they might have been seen from E', are, after reflection, seen from E as superimposed upon the direct primary and secondary bows observed from that point, E. Similarly, that light of a reflection bow which reaches E directly is superimposed upon the corresponding reflected bow.

There remains the problem of finding the actual traces of the horizontal bows. For this purpose let R_1A_1 be the projection of the incident ray onto the horizontal surface, here viewed from above. To find a point of intersection of the cone of the primary bow, for instance, vertex E, axis EA, spread 42°, with the horizontal surface SS, cut this cone with a plane normal to its axis, thus obtaining a circular intersection of radius OB, to take a special case; then, on a circle of this radius, draw a chord through a point at the distance OD from the center and normal to the radius through that point: half this chord is the distance $O'D'$, $O'D''$ from (and normal to) the axis R_1A_1 to the corresponding points $D'D''$ on the horizontal primary bow. Similarly, for as many points as desired on each of the horizontal bows.

This is not, of course, the only way, nor, perhaps, the most expeditious, of constructing these curves, but, in addition to being the way those here given were constructed, it is direct and easily understood, and therefore adapted to the present purpose—to impart a clear understanding, rather than to supply a means for speedy procedure.

NITROGEN AND THE FERTILIZER INDUSTRY.*

BY

CHARLES J. BRAND,

Executive Secretary and Treasurer,
The National Fertilizer Association.

Mr. President, Members of The Franklin Institute and Fellow Guests:

May I first express my appreciation of the honor the Institute has conferred upon me by asking me to be its guest speaker this evening. I am not unmindful of the high character, wide note and distinguished ability of those who have preceded me at this forum. May I also express the hope that the facts that I shall relate may command your attention and consideration, even if my presentation of them may not fitly or fully express their interest and importance.

There are many ways in which we might consider the use of nitrogen in modern industry and agriculture. It is not easy to decide which facts out of myriads may prove most interesting and challenging to an audience interested in all endeavors to promote the general economic welfare. I will begin by setting forth some facts relating to nitrogen itself, and will then broaden the view by considering the use of other essential plant foods, and finally will make a detailed statement regarding the modern development of nitrogen fixation and its value in peace and war.

THE NATURE AND IMPORTANCE OF NITROGEN.

Nitrogen, a colorless, tasteless and odorless gas, was discovered by Rutherford, an English chemist, in 1772. Because an atmosphere composed of nitrogen will not support life, the French named it "azote" (a, without; zoe, life); the Germans called it "Stickstoff" (a substance that chokes). Nitrogen is one of the most widely diffused of the elements. It constitutes four-fifths of our atmosphere, in which it occurs not in combination but in a balanced mixture with other

* Presented at a meeting held Thursday, March 14, 1929.

gases, chiefly oxygen. It is an essential constituent of our most destructive explosives and of some of our most deadly poisons. In its many forms, simple and complex, it supplies food for plants, animals and man. Indeed the proteins, which are nitrogenous compounds, are indispensable constituents in the human diet. In chemical technology, where it is used largely in the form of nitric acid, it is employed in the manufacture of dyes, of substitutes for silk and leather, of photographic films and of many other products. It is also used in the manufacture of artificial ice and in cold storage and household refrigeration.

Nitrogen is indispensable in both peace and war. In war it is a destructive, death-dealing explosive; in peace it is used constructively in mining, quarrying, clearing land for cultivation and road building. As a plant food it is of paramount value for application to soils that have had their natural fertility exhausted.

Taking the world as a whole, agriculture uses approximately 80 per cent. of all the inorganic nitrogen produced. The proportion used in our own country is smaller, because our soils have not yet been so greatly exploited as those in the older parts of the civilized world. With us only 60 per cent. of the inorganic nitrogen produced is consumed by agriculture, 40 per cent. being used in chemical industries.

DEVELOPMENT OF THE ART OF FERTILIZATION.

I shall not attempt to trace the history of the world's agriculture—of the development of crop plants, domesticated animals and the art of fertilization. At some time early in the history of the human race it was discovered, probably by accident around graves, that organic matter introduced into the soil produces luxuriant growth and free fruiting of the seeds of the wild plants that provide a part of the food of land animals. The Greek, Roman, Mesopotamian, Chinese, Hebrew and other early writings show a gradual development of the application of fertilizing materials to soil to promote the production of food for man and domestic animals. Cato, Virgil, Columella and Pliny make many references to the use of fertilizing substances. The ancient Chinese encyclopedias, dating back to periods no less than 1200 years before Christ,

when China already had a fully developed agriculture, likewise leave no doubt as to the relatively common knowledge that crop wastes, animal and human manures and other substances containing organic materials are useful to fertilize land.

It was not until many centuries later, after the blight of the Middle Ages, during the Renaissance, that a more conscious and thorough knowledge of the art of fertilization began to develop. By the beginning of the seventeenth century, many fertilizing materials had come into use, including not only dung but marl, green manure, lime, ashes, rags, wool, bones, horns, feathers, hoofs and fish. Then, for a period while the art of tillage was being learned, apparently less progress was made in the discovery of useful fertilizing substances. Indeed, it was not until Liebig, the great German agricultural chemist, made his classic investigations, in the period around 1840, that a new era of such progress was begun. Liebig not only made noteworthy researches but collated and summarized the knowledge contained in the available literature of past centuries.

THE AGRICULTURAL TRIAD.

It was not an accident that the triad which we are about to consider was found to be of great service in plant nutrition. Liebig's analyses first disclosed the prime necessity of nitrogen, phosphorus and potassium in the metabolism of plants. Of these three elements undoubtedly the most essential is nitrogen, although the other two are almost invariably associated with it, particularly in American agronomic literature, in any consideration of plant nutrition. This triad is of intrinsic interest not only because of its economic value but because of the individual peculiarities of each of its members.

Nitrogen is one of the most inert gases and is widely diffused, but despite its universal occurrence it was not isolated until 1772, and the fact that it is not a "permanent" gas was not discovered until 1878. Phosphorus ignites spontaneously in the presence of air and forms poisons so deadly that the laws of most nations forbid the use of one of its forms in the manufacture of matches. When the metal potassium is dropped into water, it produces a flame.

Neither one of the three members of this triad occurs in nature in a form that can be directly taken up by crops, and

consequently it has become almost a fixed habit to speak of nitrogen in the form of ammonia or nitrates; of phosphorus as phosphoric acid, the pentoxide, or as phosphates, and of potassium as potash, the oxide.

More recently other substances are coming to play important parts in agriculture. Among these are copper, manganese, boron, zinc and magnesium.

Commercial chemical fertilizers contain one, two or all three of the essential plant foods, and some that are used for fertilizing certain crops and soils contain also other substances that may be deficient in quantity or unavailable in form in the soil to be fertilized.

Nitrogen, usually considered as ammonia, increases the growth of stem and leaf, promotes the tillering or stooling of grasses and grains, augments the growth of new wood on apple, peach and other fruit trees, and in general produces luxuriance of foliage, vigorous growth, and the healthy green color seen in crops that produce good yields of high quality.

Phosphorus, available for the growing plant in the form of phosphoric acid, produces vigorous growth of roots early in the season and insures early ripening. Its value may be seen in its effects on the American corn crop, of which we produce about three billion bushels annually, for phosphoric acid, applied in the form of superphosphate, shortens by a week or more the period required to get mature grain. The opportunity thus afforded for maturing a crop before the autumn frosts may mean the difference between a crop of which 80 to 90 per cent. is merchantable and one of which only 50 to 75 per cent. is merchantable.

Potash increases greatly the formation of starch and helps to make heavy, flinty grains, such as are most desirable in milling and baking. It also stiffens the stems of grasses and grains, increasing their ability to bear heavier crops without the "lodging" that occurs when the ear of the grain is too heavy for the culm that bears it. In many crops potash also increases the power of the plants to resist disease.

PROPORTIONS OF THE ELEMENTS OF THE TRIAD IN FERTILIZER.

The elements of the triad must be used in fertilizer in suitable ratios one to another in order to insure increased

production and optimum quality. A given fertilizer is usually described by a series of three numerals, such as 3–9–3, 4–8–4, 2–12–6, 5–15–5, which express the proportions in which the elements of the triad have been combined in it. Probably no less than a thousand of such combinations are in present use, a number that is grossly excessive and that the industry is trying to reduce by a program of simplification. The series of figures thus used states the percentage of each plant food in an analysis, giving them in the order of (1) nitrogen, (2) phosphoric acid and (3) potash. The figure for nitrogen usually represents ammonia, of which only 82.25 per cent. is nitrogen as such. Thus, a 3–9–3 fertilizer contains 3 per cent. of ammonia, 9 per cent. of phosphoric acid and 3 per cent. of potash. In such a fertilizer the ratio of the plant foods to one another, as distinguished from the percentages, stated in the same order, would be 1–3–1, 1–2–1, 1–6–3. Upon the series of ratios can be built a group of analyses that would probably extend far beyond the needs imposed by the diversity of soils and crops. Practical experience has taught that under given conditions the best results are obtained by using specific ratios.

A STRIKING ILLUSTRATION OF THE EFFECT OF FERTILIZATION.

The efficacy of chemical plant food in increasing the yield and quality of a crop is shown by the results of experiments made in growing onions on peat soils by the State Agricultural College and Experiment Station of Michigan. Nitrogen was

Results of Experiments in Growing Onions

Pounds of Fertilizer Applied per Acre (Broadcast).	Marketable Onions		Percentage of Immature Onions.	Percentage of Bulbs Sprouted by May 15.
	Bushels per Acre.	Average Weight per Onion, Ounces.		
No fertilizer	65	1.2	82	36.4
Muriate of potash, 500 pounds	141	1.7	72	15.2
Superphosphate, 750 pounds	217	1.5	32	51.0
Phosphate, 750 pounds; potash 500	571	2.6	12	11.5
Nitrogen, 300 pounds; superphosphate, 750, and potash, 500	730	3.3	7	13.4

not used alone in the experiment, but its effect would have been small unless it had been used with one or both of the other members of the triad. The average results of the experiments, which were made for six years, from 1922 to 1927, inclusive, are shown in the preceding table.

Note not only the astounding progressive increase in quantity from 65 bushels per acre with no fertilizer to 730 bushels per acre when nitrogen, superphosphate and potash were used in complete fertilizers, but the astonishing fact that the number of immature onions decreased from 82 per cent. where no plant food was used to 7 per cent. where a complete chemical fertilizer was used.

We really should not be astonished at this result, however, for we have ample other illustrations of the power of chemicals to modify the metabolism of organisms. Perhaps the most striking illustrations of this power may be found in the internal secretions of human beings. For example, Dr. Graham Hoskins reported that the hormone known as epinephrine, obtained from the suprarenal glands and also made synthetically, is readily detectable by biological assay in a dilution of 1 part in 300,000,000. This means that one ounce of epinephrine crystals dissolved in 5,000,000 gallons of water can be detected. Hoskins put it more picturesquely by saying that to produce this degree of dilution "the contents of 40 miles of water carts, each holding 625 gallons and deployed 200 carts to the mile, would be required."

OCCURRENCE OF NITROGEN.

Dr. J. G. Lipman, in an address delivered in 1927 before the First International Congress of Soil Science in Washington, estimated the quantity of nitrogen in the soils, forests, and animal and human population of the world as follows:

Soils	40 billion tons
Forests	592 million tons
Animals	9 million tons
Human population	2 million tons

As most of the world's nitrogen lies near its surface, these figures might seem to indicate an adequate supply, but nitrogen is more quickly exhausted from soils, perhaps, than any other element of plant food. The peat deposits of the

world contain about 3,620,000,000 tons of nitrogen, and the coal deposits contain 98,000,000,000 tons. Our truly inexhaustible supply of nitrogen is in the atmosphere. There are about 39,000 tons of nitrogen over each square acre or about 25,000,000 tons in the air over each square mile. There are four main sources of nitrogen for agriculture and industry:

1. Organic substances, such as cottonseed meal, packing and rendering plant tankages, dried blood, fish scrap and other organic waste materials. These have grown more and more valuable as animal food, and hence less and less available for use in producing crops. Consequently only those of the lower grade are now available to the fertilizer industry.

Different compounds of nitrogen supply that element to plants at different rates, the rate depending on the rapidity with which the microorganisms in the soil attack the compounds and make the nitrogen available for the use of the plants. The makers of fertilizer use different carriers of nitrogen in plant food prepared for different soils and crops. By the use of proper carriers the plant is fed not only when the seedling first germinates and the cotyledons are thrust up through the soil, but during the later stages of the growth of the plant up to the time of its full fruition. Nitrate of soda provides nitrogen quickly. The nitrogen in sulphate of ammonia is somewhat less quickly available, because the ammonia must first be changed to nitrate by the microorganisms in the colloids around the particles of soil and in the soil solution. Organic ammoniates provide nitrogen for the plant still more slowly.

On certain soils and for certain crops it is essential that some of the nitrogen be supplied by organic materials. This is particularly true of the tobacco crop. At present only about 15 per cent. of the nitrogen in commercial plant foods is obtained from organic material. The remainder is obtained from chemical by-products in the form of sulphate of ammonia, and from the fixation of atmospheric nitrogen. In 1913, 42 per cent. of the ammonia supplied to plants in the United States was obtained from organic material; in 1926 the quantity so supplied amounted to 22 per cent.

2. Nitrate of Soda from Chile. For several decades before 1900 the largest source of nitrogen for use in agriculture and

the chemical industries was the natural deposit of nitrate minerals in Chile. Nitrate was first shipped from Chile in 1830, but it was not at once used in agriculture. As a matter of fact the art of producing crops by the use of artificial fertilizers is less than a century old. It was not until 1840, 89 years ago, that von Liebig published his pioneer work on "Organic Chemistry in its Application to Agriculture and Physiology," and the thought of previous centuries on the use of artificial promotors of plant growth seems to have come to a sort of focus around 1840. It was just after this time that the production of ammonia salts, including sulphate of ammonia, in great quantities as a by-product of the manufacture of gas was begun. The production of these salts has continued to grow until the present time, and they are now among the most commonly used chemical plant foods.

It was also in 1840 that the first South American guano was shipped from Peru to Europe. Its use grew rapidly, because it produced marvellous results. Its great value was due to its content of quickly available nitrogen in the form of ammonia, ranging from 5 to 14 per cent. according to the deposit from which it was obtained, and to its content of phosphoric acid, ranging from 10 to 25 per cent.

At this time also Sir John Lawes was developing his process of producing available phosphoric acid from natural rock phosphates by treating them with sulphuric acid. He patented his process in 1843. The first potash shaft was sunk in the Stassfurt district, in Germany, in 1851. The Germans were not seeking potash but good commercial supplies of common salt, the discovery of potash salts being purely an incidental result of their work. The systematic exploitation of the German deposits, however, was not begun until 1861.

The development of the Chilean nitrate deposits is of more than passing interest, for it shows what may happen to an industry based upon a natural resource that constitutes a monopoly when the chemist applies himself to the problem of finding independent supplies. By 1885 75 per cent. of the total nitrate nitrogen used in the world was shipped from Chile. By 1900 this percentage had dropped to 50, and by 1925 to less than 25, which is nearly the percentage now used.

The total consumption of nitrogen, however, has been increasing by leaps and bounds.

In 1898 Sir William Crookes expressed a fear that in a few decades—indeed, by 1931—the crops of the world would be suffering so much from nitrogen starvation as to threaten world hunger unless some new means of supplying nitrogen to agriculture could be found. His statement of a fear might almost have been construed as a prophecy, for already the nations of Europe, particularly Germany, England, France and Italy, are practically free from the necessity of importing Chilean nitrate, and by 1932 the United States will be similarly free from the need of importing nitrogen for making explosives in a time of war and for use in agriculture in a time of peace.

Since Sir William made his statement new deposits have been discovered in Chile, so that even after nearly 30 years it is now estimated that the Chilean deposits will supply the world's need at the present rate of consumption for 200 years longer.

3. By-Product Nitrogen from the Coking Process. By converting all the forms of inorganic nitrogen used in 1883 into terms of pure nitrogen, we find that the world then used about 95,000 tons, which is the equivalent of 613,000 tons of Chilean nitrate or 457,000 tons of sulphate of ammonia, the nitrogen content of the Chilean product being 15.6 per cent., and that of sulphate of ammonia being nearly 20.8 per cent. By 1900 the world used 330,000 tons of nitrogen; by 1913, 750,000 tons; by 1923, 925,000 tons, and at present about 1,500,000 tons. By 1913 the production of sulphate of ammonia had become so great that it represented 37 per cent. of the world's consumption; by 1926, it had risen to 50 per cent., a proportion which, in consequence of the growing production of synthetic compounds, will probably not be much exceeded in the future.

Coke and gas plants are practically the sole source of ammonium sulphate. New by-product coke ovens are rapidly replacing the wasteful old beehive ovens. About 90 per cent. of our production now comes from ovens of the modern type. The process of recovery is being improved, and we are now obtaining an average of a little over 22 pounds of sulphate of ammonia from each ton of coal that is coked in by-product

ovens. Inasmuch as less than 15.5 per cent. of the coal now mined is coked before burning (the production of bituminous coal in 1928 was nearly 500,000,000 tons, of which only 76,000,000 tons were coked), an increase in the production of ammonium sulphate is probable, although the percentage of its production to that of synthetic nitrogen may remain unchanged or may even decrease, because of the more rapid increase in synthetic production.

The increase in the production of ammonium sulphate in the United States can be shown at one stroke by saying that in 1915 its total production was about 250,000 tons; whereas in 1928 it exceeded 780,000 tons. During the next ten years its production will probably be increased to more than 1,250,000 tons. This increase would be equal to 125,000 tons of pure nitrogen.

Ten years ago, when the much-talked-of cyanamid nitrate plant was built at Muscle Shoals, its capacity was to be 40,000 tons of nitrogen. Since then the annual production of sulphate of ammonia alone has grown from 403,000 tons to 788,000 tons, the output in 1928. This means an increase from about 84,000 tons to 164,000 tons of pure nitrogen—almost double. As private enterprise is so adequately meeting the growing need of the country for nitrogen, it is proper here to raise the question of both the necessity and the desirability of governmental intervention, either directly or by subsidy, in the production of nitrogen by the Muscle Shoals plant.

4. Synthetic Fixation of Air Nitrogen. Two decades ago a wholly negligible quantity of nitrogen was obtained from the inexhaustible resources of the atmosphere. In the year 1929 about a million tons will be obtained from the atmosphere. This figure represents pure nitrogen in terms of world production and not substances carrying nitrogen. Expressed in terms of nitrate of soda, it would be equivalent to more than six million tons.

Self-preservation, speaking somewhat euphemistically, or, to be slightly more brutal, military preparedness, has been the motive or purpose behind the enormous increase in the fixation of air nitrogen. It is freely stated, and not without considerable truth, that Germany postponed a warlike attitude until she could, by reason of her freedom from the Chilean

nitrate beds, wage independent and effective war, even though blockaded. Every nation naturally has an ambition to be sufficient unto itself with respect to the commodities that are absolutely essential for its defense. The ambition for military preparedness has greatly benefited the farmers of the world, for in times of peace agriculture provides the only relatively sufficient outlet for the immense quantity of nitrogen that has been produced during the last twenty years.

PROCESSES OF MANUFACTURE.

Air-derived nitrogen is produced by three distinct processes, usually termed (1) the arc process, (2) the cyanamid process and (3) the synthetic process. The synthetic process really involves a number of different processes or variations of the same fundamental process. The essential features of these processes can be described very briefly.

The arc process, as its name indicates, involves the use of the electric arc in a manner not essentially different from that in which it is employed for street lighting. It is an imitation of the natural fixation of nitrogen by lightning.

The cyanamid process involves the fusing of coal and limestone to form calcium carbide, a compound of calcium and carbon. This compound is heated to a high temperature (approximately 1,000 degrees Centigrade) and nitrogen is then passed over it in great autoclaves in the presence of steam and is fixed in the mass in the form of calcium cyanamid.

In *the direct synthetic process*, the one now most widely used, a mixture of nitrogen and hydrogen, which are first obtained separately, is passed under high pressure (1,500 to 15,000 pounds per square inch) over a catalyst at a high temperature (500° to 600° Centigrade) to produce ammonia gas. This gas is condensed or absorbed, as may be desired, and is marketed either in the form of ammonia (NH_3) or aqua-ammonia (NH_4), or is combined with other elements to form sulphate of ammonia, synthetic nitrate of soda or other materials.

Some of the synthetic processes now in use are the Haber, the Haber-Bosch, the Casale and the Claude. In these various processes different methods are employed to produce the pure nitrogen and the hydrogen required for the catalytic

process, but the ultimate result is substantially the same. The Fixed Nitrogen Research Laboratory of the United States Department of Agriculture has devised one of the methods of fixation now used, and in particular has improved catalysts and increased our knowledge of them.

POWER REQUIREMENTS OF SYNTHETIC PROCESSES.

Recently Sir Alexander Gibbs, President of the Institute of Chemical Engineers of England, estimated that the arc process, which recently has been used only in Norway, where hydroelectric power is very cheap, and even there its use is diminishing, demands about 80,000 kilowatt hours per ton of nitrogen fixed. Other authorities have stated that this process requires only 60,000 kilowatt hours. Gibbs states that the cyanamid process requires about one-fourth of the electrical energy of the arc process, or from 16,000 to 20,000 kilowatt hours. The direct synthetic process requires about one-sixteenth of the power required by the arc process and one-fourth of that required by the cyanamid process. It uses from 4,000 to 5,000 kilowatt hours per ton of nitrogen fixed.

These facts are worthy of careful thought in connection with the present effort to reconstruct and modernize at government expense the cyanamid plant at Muscle Shoals. Why should we undertake to put into use a plant that requires 16,000 to 20,000 kilowatt hours per ton of nitrogen if the modern process requires only 4,000 to 5,000 kilowatt hours, particularly in view of the fact that it will cost from $10,000,000 to $20,000,000 to modernize the plant?

TREND OF THE INDUSTRY AS TO PROCESSES.

In 1913 seven plants in the world were using the arc process and producing 19,800 tons of nitrogen. At that time this quantity represented nearly 32 per cent. of the total output of synthetic nitrogen. In 1926 the same seven plants were still producing nitrogen, but with increased capacity and greater efficiency. They were then making 40,500 tons of nitrogen, yet that quantity was only 5.5 per cent. of the total synthetic nitrogen made in the world.

In 1913 fifteen plants were producing nitrogen by the cyanamid process and their total product was 36,000 tons, or 57.4 per cent. of the world's total output of synthetic nitrogen.

By 1926 the number of plants had increased to 28 (nearly double) and the production had increased to 174,000 tons, but the percentage of the total nitrogen produced by this process had dropped from 57.4 to 23.7.

In 1913 (note the contrast) only one plant was producing nitrogen by the direct synthetic process. It was making 6,000 tons of nitrogen, only about 11 per cent. of the total synthetic output, but by 1926 the number of plants producing nitrogen by this process had risen to 49 and the total production had increased from 6,000 to 519,000 tons, or 70.8 per cent. of the total synthetic nitrogen produced in the world.

The figures for 1926 are given because they are the most readily available and perhaps more authoritative than those for later years. The same trend continues, even with some accentuation, for if the market will absorb it Germany will produce this year about 600,000 tons of nitrogen by direct synthetic processes.

IMMENSE DEPLETION OF OUR SOIL RESOURCES.

Almost no layman and few agronomists realize clearly the extent to which crop production and erosion are making drafts on the nation's soils. Mr. H. H. Bennett, of the United States Department of Agriculture, recently made a statement from which we may infer that it takes 10,000 years for Nature to form a foot of fertile soil from the rocks of the earth's crust. Every year we carelessly and thoughtlessly permit erosion to wash away a vast amount of the soil that has been formed during a period covering more than twice our known historical era. According to Bennett erosion takes 126 billion pounds of fertilizing elements annually from our soils, which is 20 times as much as that removed by all of our crops. He estimates that the plant nutrients thus removed could not be replaced by an expenditure of two billion dollars a year.

The National Industrial Conference Board recently estimated that crops remove annually 9,000,000 tons of nitrogen from our soils. Only about 40 per cent. of the nitrogen thus removed is restored by the use of manures. An enormous quantity of both phosphoric acid and potash is also removed by crops, which cause a loss of plant food above that restored of about 5,900,000,000 pounds, valued at $400,000,000 annually.

It is not difficult to see what an annual overdraft of $2,400,000,000 on our bank of soil resources ultimately means to the country if continued for many years. Declining returns from agriculture have already served notice to farmers and economists that even the richest soils are not inexhaustible. Our agricultural plant is depreciating and no sinking fund is being provided to cover its depreciation. Many blame the farmer for the increasing loss. Liebig once said, "Agriculture is of all industrial pursuits the richest in facts and the poorest in their comprehension." He was no doubt hurling a shaft at the German farmer of the middle of the nineteenth century. His statement has less force now than it had then, and even then it was not altogether fair, nor would it be fair if applied to the American farmer.

THE FARMER'S HANDICAPS.

For a long time farmers have operated at a disadvantage in exchanging their goods and services for the goods and services of others. The purchasing power of farm products in terms of other commodities has been so low as to create a handicap that they could not overcome and that lies at the root of the present demand for agricultural restoration, or farm relief, as it is commonly called. Many a farmer would have a better home, would educate his children better, would buy better machinery and undertake a program of soil improvement, including the use of chemical plant food, if he could only gain a fair net income. Of the commodities that he must use only feeds and fertilizers are now cheaper than the products of his farm, taken as a whole. The prices of the commodities and services he must buy from others are from a few per cent. to more than 100 per cent. higher than in 1913. His labor costs him about 70 per cent. more; some of his taxes are more than 100 per cent. higher; his railroad transportation charges are from 75 to 100 per cent. greater, and the prices of many other things are much higher. We therefore need not wonder at the astounding continued depletion of our soil resources, despite the fact that the farmer is aware of the loss. He cannot solve the problem; it is too big for him. We need a national agricultural policy in which all the elements of our population, from producer to consumer, must share if it is to be effectively carried out.

Not all the plant food and particularly not all the nitrogen that is removed by crops and erosion need be returned through agricultural practices involving the growing of crops with associated nitrogen fixation, or through restoration by the use of natural manures or commercial fertilizers. Every year the electric discharges shown by lightning cause the fixation of no less than 100,000,000 tons of nitrogen, which through rain and snow ultimately finds its way into the water and soil. Unfortunately, the arable acres receive only as much nitrogen as equal surfaces of the ocean and of the barren deserts.

NITROGEN FIXATION IN SOILS BY BACTERIA.

Competent soil bacteriologists estimate that as much as 200 pounds of nitrogen per acre may be fixed in the soil by the bacteria that live on the roots of many legumes—members of the pea family. The nitrogen in organic matter is complex and is therefore not directly available for the use of plants. It must first be broken down into simple water-soluble compounds. This action involves the conversion of combined nitrogen into ammonia, although, perhaps, some ammonia is taken up as such. A fraction of the vast bacterial population of the soil changes the ammonia to nitrites, and these are then changed to nitrates, which are directly available to plants as food.

Certain plants are more efficient than others in obtaining nitrogen from the air and soil. Especially efficient are the members of the legume family, to which belong not only our familiar garden peas and beans, but also the clovers, alfalfa, the vetches, soy beans, cow peas, and many other garden plants, as well as hundreds of species of trees, like the locusts, the cassias and the acacias. The apparent power of these plants to fix atmospheric nitrogen is due to their symbiotic relations with a group of nodule-forming and nitrogen-fixing soil bacteria. If you pull up a bean or pea or clover plant and examine it, you can find hundreds of little tubercle-like nodules on its roots. These nodules are the homes of billions of colonies of bacteria. We little realize the immensity of the number of inhabitants of our soils, even of those of the desert. Dr. S. A. Waksman of Rutgers University reported in 1927 that the surface portion of a brown loam soil contains 1,518,000,000 microorganisms per gram. Dr. H. J. Conn

found as high as 800,000,000 bacteria alone in a gram of soil. Numerous fluctuations take place in their numbers in a short time. A sample of soil containing 7,500,000 bacteria at one time as determined by the culture method had decreased in 16 days to but a little more than 2,000,000. Great variations occur in different parts of the same plot of ground. Waksman reported that a bacterial count of a small plot of earth showed a range from 8,000,000 to 25,000,000 bacteria per gram of soil. The number varies also in soil of different types, at different depths, at different seasons of the year and in soils that have received different agricultural treatment. Great differences also occur with variations in the acidity or alkalinity of the soil.

OUTSTANDING ACHIEVEMENTS OF THE LAST TWO DECADES IN THE FIXATION OF NITROGEN FROM THE ATMOSPHERE.

In the fixation of nitrogen the World War stimulated much greater progress in Europe than in the United States, and the European experience may show fairly well what may be done in the United States.

In 1913 the world production of nitrogen was as follows:

	Tons N.
Chilean nitrate	429,897
By-product ammonia	319,667
Synthetic ammonia	90,491
Total	840,055

Mr. H. R. Bates, in a paper read before the Nitrogen Symposium of the American Chemical Society in 1928, estimated the production capacity of the world in 1927 as follows:

	Tons N.	
Synthetic ammonia	700,000	
Norwegian salpeter	30,000	
Cyanamid	200,000	
		930,000
By-product ammonia		370,000
Chilean nitrate		320,000
Total		1,620,000

These figures represent an increase of almost 100 per cent. within 14 years. Only the stimulation of national self-defense and military ambition could have achieved such a result. Preparedness has been foremost in the minds of

European statesmen or politicians, who have given every possible assistance to their domestic nitrogen industries.

In Germany, where the most remarkable development has occurred, this encouragement has been given by the construction of government plants to be leased to private corporations at nominal rentals or transferred to them outright at very low prices. There are two plants of special interest in Germany, both owned by the great German Dye Trust, the Interessen Gemeinschaft Farbenindustrie, commonly called the I. G., one of which has a fixation capacity of 100,000 tons of nitrogen a year, and the other a capacity of about 500,000 tons. One plant is at Oppau and the other at Merseburg. In 1910 the plant at Oppau was a small experimental unit. In 1911 it was turning out only about 25 pounds of ammonia a day. In 1912 it was making about one long ton (2,240 pounds) a day. In 1914 it was making 7,000 tons of ammonia a year. In 1917 it was producing 100,000 tons of fixed nitrogen a year. This single illustration shows the possibilities of growth in the fixation of nitrogen.

In 1927 the nations participating in the manufacture of fixed nitrogen had estimated production capacities shown by the following table:

World Capacity of Nitrogen Production in 1927, in Tons.

	Synthetic.	Cyanamid.	By-Product.	Arc Process.	Total.
Germany	450,000	114,000	100,000	.....	664,000
France	116,700	53,500	5,000	.....	175,200
England	55,000	.....	100,000	.....	155,000
United States	25,000	40,000	147,000	.....	212,000
Italy	63,700	20,000	3,500	.....	87,200
Japan	43,500	20,000	5,000	.....	68,500
Belgium	22,000	.....	10,000	.....	32,000
Spain	7,200	.....	.....	.....	7,200
Poland	3,000	30,000	.....	.....	33,000
Czecho-Slovakia	4,500	6,000	.....	.....	10,500
Norway	.....	15,000	.....	46,500	61,500
Russia	7,300	.....	.....	.....	7,300
Sweden	2,500	6,000	.....	.....	8,500
Roumania	.....	5,000	.....	.....	5,000
Canada	.....	60,000	5,000	.....	65,000
Switzerland	2,200	.....	.....	.....	2,200
Jugoslavia	.....	14,000	.....	.....	14,000
	802,600	383,500	375,500	46,500	1,608,100
Actual Production	700,000	200,000	370,000	30,000	1,300,000

DEVELOPMENT OF THE FIXATION OF NITROGEN IN THE UNITED STATES.

Manufacturers and others who want to get possession of the power plants at Muscle Shoals and politicians who would be benefited or think they would be benefited by the government's operation of these plants are accustomed to belittle the progress made in the United States in the fixation of atmospheric nitrogen. In 1927 we used approximately 250,000 tons of inorganic nitrogen as a source of commercial plant food. In a time of peace our industries other than agriculture use about 100,000 tons of inorganic nitrogen a year. It would therefore appear that the total nitrogen required annually in a time of peace would be about 350,000 tons. Experts on munitions estimate that the nitrogen annually needed for carrying on a first-class war would amount to about 144,000 tons.

By the end of 1929 we shall have the capacity to produce at least 100,000 tons of synthetic nitrogen. The production of sulphate of ammonia in 1928 increased nearly 10 per cent. over that in 1927. The production in 1928 was 788,000 tons. Assuming a slower rate of increase in 1929, we may expect a production of at least 850,000 tons. With a nitrogen content of 20.8, this would amount to more than 175,000 tons of pure nitrogen. Our total capacity to produce inorganic nitrogen would therefore be approximately 275,000 tons against an approximate peace-time need of 350,000. We therefore appear to be about 75,000 tons short of covering our need of inorganic nitrogen, and the demand is still increasing. Highly satisfactory progress is being made, however, and by the end of 1932 we shall probably be measurably self-sufficient. In 1913 we produced no synthetic nitrogen whatever; in 1921 we produced 200 tons; by the end of 1929 we shall have the capacity to produce about 100,000 tons. The recent and prospective increase has been due chiefly to the breaking in of the units of the great chemical plant at Hopewell, Virginia. Six or seven other corporations are increasing their production, so that by the end of 1932 we may have a synthetic production capacity of possibly 200,000 tons. In the event of war we could easily raise this total to 250,000 by modernizing the obsolete cyanamid plant at Muscle Shoals. When we make war we are not likely to consider economy of production.

To show our progress toward freedom from foreign nitrogen, I need only say that in 1900 the United States produced 13 per cent. of its requirements; in 1910, 18 per cent; in 1913, 25 per cent; in 1928, 50 per cent. In 1929 it is estimated that it will produce 65 per cent. of its requirements, and in 1930, 80 per cent.

One of the interesting features in the progress of the past twelve months has been the direct use of liquid ammonia in the manufacture of fertilizer, a use that is a means of economy. It is shipped in tank cars to seventy-one plants, operated by some twenty companies. Both synthetic nitrate of soda and synthetic sulphate of ammonia of remarkably fine quality are also being produced.

EUROPEAN EFFORTS TO MARKET NITROGEN IN THE UNITED STATES.

Germany, England, France, Italy, Norway, Czecho-Slovakia, and other countries are producing nitrogen in excess of their own domestic consumption. The military urge, of course, is behind this great production, but in the quiet of peace some outlet must be found for the product. The United States, China, India and other countries are looked to as lands of promise. Germany, for instance, has a consumptive

Typical German Concentrated Fertilizers Containing Two or More Plant Foods.

	Nitrogen (N).	Phosphoric Acid (P_2O_5).	Potash (K_2O).	Total.
Mono-ammonium phosphate	11.6	60.6	0	72.2
Di-ammonium phosphate	20.7	52.3	0	73.0
Potassium ammonium nitrate	16	0	28	44
Urea ammonium phosphate	20	49.4	0	69.4
Potassium ammonium phosphate	5.25	54	18.5	77.75
Potassium nitrate	13	0	44	57
Leunaphos	20	20	0	40
Nitraphoska No. 1	17.5	13	22	52.5
No. 2	15	11	26.5	52.5
No. 3	16.5	16.5	20	53
No. 4	15.5	15.5	19	50
No. 5	15	30	15	60

capacity of only about 400,000 tons of fixed nitrogen and a producing capacity of more than 600,000 tons. To obtain entry to the American market, the German chemical industry, always progressive and vigorous in its policy of trade develop-

ment, has prepared a number of valuable chemical plant foods containing one, two or all three of the agricultural triad—nitrogen, phosphoric acid and potash. Without taking time to describe these products in the course of my oral statement, I insert at this point a short table giving some typical materials containing two or more plant foods.

EFFORTS TO INCREASE PLANT FOOD CONTENT OF FERTILIZERS.

We can realize the value of these German fertilizers and their high content of plant food (50 to 77 per cent.) if we remember that the combined average percentage of nitrogen, phosphoric acid and potash contained in the average American fertilizer is between 16 and 17 per cent. The fertilizer industry and the official agricultural forces of the United States have been working for many years to raise the plant-food content of fertilizers to the level now reached. As a consequence, the German fertilizers, when used in the United States, must be diluted in order to meet the present demand of the American farmer. Incidentally, their importation duty free constitutes one of the problems of the American industry.

The National Fertilizer Association has devoted ten years of earnest effort to increase the concentration in American fertilizers, but its progress has been limited by the economic condition of the farmer, the relative slowness of agricultural education, and the fact that our fertilizer-distributing machinery is not yet sufficiently perfected to place in its proper relation to the seed or the growing plant the small quantities of these concentrated fertilizers that must be applied.

MUSCLE SHOALS AND THE NITROGEN PROBLEM.

No discussion of the production of nitrogen in the United States would be complete without mention of the problem of disposing of the government properties at Muscle Shoals, Alabama. It would be like discussing Macbeth and failing to mention Banquo's ghost. During the last ten years Muscle Shoals has ranked with prohibition and farm relief in its demand for newspaper space. I have already commented on the fact that the ambition to attain military independence with respect to essential munitions of war now marks the psychology of practically all countries. The United States

has not escaped this ambition. In addition agricultural distress has stimulated the desire of farmers in all countries to obtain cheaper nitrogen, despite the fact that nitrogen is now cheaper relative to farm products than it was before the World War. Politics and propaganda of interested groups have been great breeders of distorted pictures and misleading half-truths. Great expectations have been created in the farmer's mind with a view to using his political power to get possession, in his supposed interest, of the great property at Muscle Shoals. False hopes have been raised in the farmer's mind of the benefits that may come to him from this source to relieve him of his present serious economic burdens.

The United States has almost unlimited supplies of phosphate rock for the production of phosphoric acid. Our phosphate reserve is seven to ten billion tons.

We are heavily dependent upon Germany and France for our potash salts, but we are now producing about 75,000 tons of potash (K_2O) annually, and the output can be increased, though perhaps not immediately, until it is sufficient to supply our needs. Potash deposits are being explored in Texas and New Mexico, and the greensands of New Jersey may some day, by the aid of our chemists, make us self-sufficient in potash, as we are in phosphorus.

Our situation as to nitrogen has been fully disclosed in the course of this address. We come, then, to a consideration of a sensible economic disposal of the plants at Muscle Shoals, which shall take into account the rights of private enterprise that must carry on without subsidy from the government. We now have three valuable assets at Muscle Shoals:

1. The Wilson Dam, which cost approximately $47,000,000, with its fine hydroelectric power plant, with which should be considered Steam Power Plant No. 2, built for the use of the big cyanamid plant at a cost of approximately $12,000,000.

2. Nitrate Plant No. 1, which was built at a cost of $13,000,000 to utilize a modification of the synthetic process known as the Haber-Bosch but which was never run successfully because of our lack of precise knowledge of the details of operation.

3. Nitrate Plant No. 2, the cyanamid plant, with which should be included the Waco limestone quarry, the cost of the

two together, with their incidental properties, being about $68,000,000.

PLAN PROPOSED IN MADDEN BILL.

The Madden bill, which was pending in Congress when it adjourned on March 4, proposes to turn over the properties described above to a private corporation without charge for interest except on $17,000,000 of the cost of building the Wilson Dam, the sum expended after May 31, 1922. In other words, assets that cost the United States above $140,000,000 are to be leased for a period of fifty years without rental interest except on the $17,000,000 mentioned. About eighty million dollars of new money is to be expended, and the products of the expenditure are to be turned over to a private corporation at a rental of 4 per cent. The cost of construction immediately after the war was no doubt excessive, but property representing an eventual expenditure of more than $216,000,000 is to be turned over at an average rental that will pay only about 2½ per cent. Private enterprise is supposed to compete with the company that is to be given such largess by the government.

The unreasonableness or the impossibility of such a plan is made evident by the fact that the ordinary manufacturer of fertilizer pays from 6 to 8 per cent. for all the money he borrows, both for fixed and operating capital. Furthermore, he must pay state, county and municipal taxes, from all of which the government's lessee is to be relieved. The private operator must also carry fire and other forms of insurance; the government will carry all the insurance on the plant leased. Furthermore, the fertilizer industry at present has a capacity to manufacture 10,000,000 tons of complete fertilizer, with a demand for only about 7,000,000.

Muscle Shoals is intrinsically a power enterprise. This fact is readily disclosed by the present plans. It is planned to provide dams and generating facilities in addition to those already installed, for the production of approximately 1,250,000 horsepower years of power. The lessee promises, if a group of meticulous conditions are fulfilled, to produce, after a period of several years, a maximum of 50,000 tons of nitrogen. The maximum amount of power required for such a production would be 150,000 horsepower years. As more than

a million horsepower above this requirement are to be produced, it is clearly evident that the purpose of those to be benefited is to obtain the possession and use of enormously valuable water-power plants rather than to manufacture cheap fertilizer. It should be said, however, in fairness to the company named in the Madden bill, that it does propose in good faith to manufacture a large quantity of fertilizer. The objection of the existing fertilizer industry, of which the company leasing the plant is a part, is that the plan will create unfair competition that is in every aspect un-American.

PLAN FAVORED BY THE FERTILIZER INDUSTRY.

The fertilizer industry, through The National Fertilizer Association, has suggested what it believes to be a fair and practical plan for the disposal of the plants at Muscle Shoals. Its suggestion briefly is:

1. That the Wilson Dam and Steam Plant No. 2 shall be sold or leased for the generation of power for any purpose for which there may be an economic demand. If no satisfactory bidder is found, the Engineer Corps of the War Department shall continue to produce power as it is now doing and sell it at the switchboard to the highest responsible bidders. The average income for the last two fiscal years from the sale of power at Muscle Shoals has been approximately $1,300,000 yearly.

2. That Nitrate Plant No. 1, which is a pilot-size plant, shall be turned over to the United States Department of Agriculture for technological and chemical research in nitrogen fixation, including the production of nitrates for making fertilizers on a scale sufficient for farm demonstrations under the direction of federal and state experiment station workers, but not in quantity sufficient for commercial purposes.

3. That the obsolete cyanamid Plant No. 2 shall be kept in stand-by condition by the War Department for from one to three more years, and that it shall then be sold for scrap or otherwise, just as other surplus war materials have been sold, but that the nitric acid or oxidation part of the plant shall be retained by the War Department for such value as it may have for national defense, particularly in the manufacture of powder.

The cyanamid process, as has been shown, is wasteful of power, requiring no less than 16,000 kilowatt hours per ton of nitrogen, whereas the synthetic process requires only 4,000 to 5,000. The plant at Muscle Shoals has been built ten years, and during that time the art of nitrogen fixation has progressed with what might fairly be termed meteoric rapidity. There is a constantly growing need of power for all kinds of technological and industrial purposes in the Muscle Shoals area. It would be an economic crime to waste this valuable resource in an obsolete plant using an obsolescent process. It would cost between $10,000,000 and $20,000,000 to modernize the plant, and for that sum of money a new synthetic plant of greater capacity could be built near to coal, which is more important for nitrogen fixation than water power because it is a valuable source of the hydrogen that must be used in the more efficient catalytic synthesis.

The United States government should encourage, not throttle, private enterprise in the remarkable progress it has already made in nitrogen fixation. It should protect a service-giving industry that is indispensable to American agriculture and not threaten it with competition from a governmentally subsidized corporation drawn from its own ranks. It should encourage private endeavor in every possible manner, and should not engage in competition with its citizens except, as Lincoln said, when it is necessary to do something for the citizen which he cannot do for himself.

ECONOMIC BENEFITS OF FERTILIZATION.

The economic returns from the use of commercial plant nutrients can be lllustrated in many ways. I have already given a single illustration of the effects of their use on onions grown on peat lands in Michigan. In order to leave a more accurate and generally applicable impression, I will briefly show how much the use of fertilizers may increase yields.

There are about 6,250,000 farms in the United States. In 1928 about 2,250,000 of these farms used artificial plant food in some form.

The results of official experiments, many of them carried on in large commercial field tests, and of the experience of hundreds of thousands of farmers show that, as a general

average, one dollar invested in fertilizer returns three dollars in increased crop values. The following examples show the increases that may be gained by the use of fertilizer.

One ton of fertilizer, costing approximately $35, produces an increase of 75 to 125 bushels of potatoes, worth $85 to $140 (5-year average, farm price on December 1).

One ton of fertilizer, costing approximately $30, produces an increase of 1,500 to 2,000 pounds of seed cotton (approximately one-third lint and two-thirds seed), worth $115 to $155 (5-year average, farm price on December 1).

One ton of fertilizer, costing approximately $30, produces an increase of 70 to 100 bushels of wheat, worth $86 to $119.

One ton of fertilizer, costing approximately $30 to $40, produces an increase of 1,000 to 1,400 pounds of tobacco, worth $200 to $275 (5-year average, farm price on December 1).

Another way of expressing the economic benefits to be obtained by the use of fertilizer is afforded by the official records of the Ohio Agricultural Experiment Station, which found that an hour's labor on unfertilized land produced a little over a half bushel of corn; whereas an hour's labor on fertilized land produced over a bushel and a half. An hour's labor on unfertilized oats produced two bushels; on fertilized oats, four bushels. On unfertilized land an hour's labor produced 1⅛ bushels of wheat; on fertilized land it produced more than 3 bushels. Unfertilized cotton in South Carolina yielded about 500 pounds of seed cotton per acre; immediately adjacent land treated with 800 pounds of chemical plant food yielded nearly 1,200 pounds of seed cotton per acre.

PERIOD OF CROP NUTRITION IN AMERICAN AGRICULTURE.

Modern agriculture in western Europe and the United States began with Jethro Tull, who was born in 1700 and died in 1760. The period of progress that was ushered in by Tull's discoveries and practices lasted until about the end of the Napoleonic wars, in 1815. It was characterized by new crops, improved methods of cultivation, pronounced advancement in animal husbandry in all of its phases, and the substitution of individual farming for the ancient system of commons.

The period of greatest advancement in American agriculture, which was reflected in European agriculture, began with the invention of the harvester and the many other modern farm implements that are now commonplaces to all of us. This period of mechanization still continues, and in its modern phases is marked by the development of the tractor, the combine harvester and many types of improved cultivating and other machines. It is also marked by notable improvements in the control of plant and animal diseases, in the breeding of superior varieties of plants and animals, and in the increased use of power, as well as by other similar evidences of progress.

The agricultural depression of the last decade has forced the American farmer to recognize the necessity of intensive cultivation. His future ideals will be to reduce the cost of production and to obtain larger yields. Our present agricultural condition is not new, for despite the fact that our progress in the use of commercial plant food has been slow, we are now using between 7,000,000 and 8,000,000 tons of fertilizer a year. We made our first practical application of fertilizer in the decade between 1840 and 1850, almost immediately after the discoveries of Liebig in Germany and Lawes in England. So we may properly say that we are now decidedly over the threshold of a period of scientific plant feeding, a period not unlike the period of scientific animal feeding that has been staged during the last fifty years. In this unfolding scene nitrogen will play a most important part

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

PAPER TESTING STANDARDS.

At the annual meeting of the Technical Association of the Pulp and Paper Industry held in February, B. W. Scribner of the Bureau of Standards, chairman of the paper testing committee, presented a report of the activities of the committee for the past year. The following is a summary of the report:

The committee is still concentrating on the development of official association testing methods. During the past year three new methods were completed—gloss, opacity, and bulk—and the first two have been adopted by the association as standards. The adoption of these two optical methods gave considerable impetus to their use as a part of the testing routine for control of paper-making processes.

Considerable development work was done on specific projects allotted to four different subcommittees. Under the leadership of E. O. Reed, much progress was made in further standardizing a method for measuring the resistance of papers to printing inks, and a satisfactory method for this important determination will no doubt be available in the near future. The subcommittee on microscopical methods, headed by Prof. C. E. Libby, made an intensive study of the "dot" method for determination of fiber composition. They proved that this modification gives increased accuracy, particularly in the case of the more inexperienced analyst. Miss H. U. Kiely's subcommittee on chemical methods obtained test data which will lead to considerable improvement of the present official methods for quantitative determination of starch and paraffin. Progress was made in developing a method for quantitative determination of acidity and an improved method for detection of formaldehyde. For acidity, it is believed that a modified Kohler-Hall method, whereby a water extract of the paper is tested in the presence of the

* Communicated by the Director.

fibers in an atmosphere freed of carbon dioxide, will permit much greater accuracy. The subcommittee on permeability to liquids, Allen Abrams, chairman, obtained considerable valuable data through coöperative tests by various laboratories, of the degree of concordance to be expected in determination of degree of sizing and grease resistance. For the former, the methods proposed by the Bureau of Standards gave very promising results. Various modifications of H. A. Smith's method for grease resistance gave rather conflicting results and considerable further development of it is necessary.

During the current year, in addition to the continuing work indicated, development work will probably be initiated on determinations related to permanence, such as alpha cellulose, copper number, effect of light, and effect of heat.

COÖPERATIVE DEVELOPMENT OF PERMANENT LEDGER PAPER.

A STRIKING example of the value of correlating laboratory tests and mill practice was recently experienced. At the request of a paper manufacturing concern, the bureau is coöperating with them in improving the quality of a rag fiber permanent ledger paper found to be deficient in some respects. Exhaustive permanence tests showed that the paper was exceedingly strong, having a folding endurance of around 25,000 folds. When subjected to the heat treatment, however, the paper darkened, increased excessively in copper number, and decreased excessively in alpha cellulose, all of which indicated that the paper contained degraded celluloses and therefore that it would be of doubtful permanence. As the highest grade of raw materials was used in its manufacture, it was surmised that some detail of the manufacturing processes was faulty. The original copper number was low, therefore the cellulose degradation was attributed to either excessive hydration in beating or to the high rosin content. The manufacturer made a subsequent paper with exactly the same raw materials but with much milder beating, as is indicated by the lower folding endurance of 6,000 folds. This paper in all respects appeared to have the maximum quality for permanence as it was practically unaffected upon heating for 72 hours at 100° C. Apparently excessive hydration was the prime cause of the previous poor quality.

TRANSPARENCY OF TRACING CLOTH TO ULTRA-VIOLET LIGHT.

IN view of the inquiries received regarding the transparency of tracing cloth, about which there has been considerable publicity in the press, transmission tests have been made on this material.

Tracing cloth consists of thin, loosely woven fabric of linen or cotton, impregnated with a highly soluble, transparent starch. The drawback in the use of such a material for a window is the high solubility of the sizing which dissolves when touched with water, leaving the cloth in a rough condition which is then no better than other thin, bleached, loosely woven material, such as, for example, nainsook or balloon cloth.

The bureau has determined the transmission of tracing cloth and finds that the total ultraviolet of wave-lengths 250 to 310 millimicrons diffusely transmitted through a new sample of tracing cloth amounted to about 26 per cent. before wetting, and 14 per cent. after removing the sizing and drying the cloth.

In Table 1 of Bureau of Standards Research Paper No. 6, which may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents per copy, are recorded the ultraviolet transmissions of a sample of balloon fabric (transmission, 21 per cent.), of batiste (transmission, 16 per cent.), and of nainsook (transmission, 31 per cent.), showing that tracing cloth is not superior to other fabrics for use as a window for transmitting ultraviolet radiation.

EFFECT OF SERVICE ON THE ENDURANCE PROPERTIES OF RAIL STEELS.

A SERIES of tests has been carried out to determine the effect of service on the endurance properties of rail steels, and the complete report will appear in a forthcoming number of the *Bureau of Standards Journal of Research.*

In a previous report (Technologic Paper No. 363, obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 35 cents per copy) data were given on the endurance properties of steels from new rails from 11 distinct heats. An hypothesis based on the

phenomena of "overstressing" and "understressing" was presented whereby it was considered possible to determine whether the steel of the rails in service was subjected to stresses greater or less than its endurance limit by a comparison of the endurance limits before and after service.

Through the coöperation of the Baltimore and Ohio Railroad and the Canadian Pacific Railway, a total of 18 rails were removed from track after being subjected to over 20,000,000 and 12,000,000 tons of traffic, respectively. These were principally *A* and *B* rails from 6 heats tested before service, and 1 heat not previously tested.

The endurance properties were determined in the same manner as for the rail steels before service.

In the rails returned from service on the Baltimore and Ohio Railroad the endurance properties of the steel were found to be the same as before service.

Tests were made to determine the effect of appreciable surface flow and consequent hardening of the top of the head of the rail in service on the endurance properties of the steel in that rail. No evidence was found of any "overstressing" or "understressing" having occurred.

It was concluded that under the service conditions to which the rails were subjected on the Baltimore and Ohio Railroad the steel in the head of the rail was not subjected to fatigue stresses greater than its endurance limit.

The results of similar tests of rails after service on the Canadian Pacific Railway were not as definite in their indications. In most cases the test specimens showed a very marked "scatter" in endurance properties indicating appreciable inhomogeneity in the steel. This "scatter" was found to be due to the presence of groups of minute transverse cracks or so-called "shattered zones" in the rail as removed from service.

Microscopic examination showed the cracks to be principally transcrystalline but in a few instances evidence of intercrystalline failure was apparent indicating failure while the metal was hot, that is, before service.

Examination of a new rail from one of the same heats showed the presence of shatter cracks; premature failure of a fatigue test specimen from a new rail of the same heat was also found to be due to the presence of an internal crack.

It was therefore, believed that the cracks found in the service rails, and consequent wide scatter of results obtained in the endurance tests, may have been due to cracks present in the new rail and not to conditions which originated in service.

In cases where the endurance tests were not affected by the presence of cracks, the endurance properties were found to be comparable with those given by tests before service, indicating that service had not imposed repeated stresses greater than the endurance limit of the steel. It was concluded that fatigue failure in service, transverse fissures, spread from a pre-existed nucleus.

Comparative tests were also made on steel from a rail which failed in service due to a transverse fissure, and an adjacent rail in track which had been subjected to the same traffic conditions. The endurance limit of the steel from the fissured rail was found to be appreciably greater than that from the unfissured rail from which it was concluded that failure due to transverse fissure is not due to fatigue stresses alone but develops from a preëxistent nucleus.

A MODIFIED METHOD FOR THE DECOMPOSITION OF CERAMIC SILICATES FOR CHEMICAL ANALYSIS.

THE method ordinarily used for decomposing silicates preparatory to their chemical analysis consists of fusing them with several grams of sodium carbonate. In connection with the routine analysis of some china clays, fireclays and other aluminous silicates, the bureau has recently used a method for decomposing them which is not well known, but which apparently can be used quite advantageously for certain silicates.

The method consists essentially of intimately grinding together a weighed amount of the silicate with not more than an equal weight of sodium carbonate, transferring the mixture to a platinum crucible and heating it for about an hour over a Tirrill or Meker burner. Ten milliliters of water are added to the cooled crucible, which is then placed on a steam bath. After a few minutes ten milliliters of hydrochloric acid are added and the mixture is evaporated to dryness. Ten milliliters of concentrated hydrochloric acid are added, after

which the crucible is filled practically full of water, digested for a few minutes and the dehydrated silica filtered and washed. The combined R_2O_3 is precipitated and reprecipitated in the usual manner and the analysis completed in the ordinary way.

The amount of sodium carbonate required and the temperature of burning depend on the nature of the silicate. The most desirable condition is obtained when neither sufficient sodium carbonate nor heat is used to yield a glassy or vitrified mass in the crucible. For different materials the amount of soda ash may range from 0.2 to 0.5 grams and the temperature from that of a dull red to the highest temperature obtainable with a Meker burner. No recommendation can be made at present as to the amount of soda ash that should be used or the temperature required, but a few trials by chemists dealing with materials of a similar nature will indicate the most desirable combination.

The evidence on which the value of this procedure is based is that the non-volatile residue after treating the dehydrated silica with hydrofluoric and sulphuric acids generally does not exceed 1 mg. A decided advantage in this procedure is that the decomposition of the silicate and the dehydration of the silica can be carried out in the crucible in which the "sintering" was done. The greatest advantage, however, lies in the fact that the amount of sodium oxide to be washed out of the various precipitates may in some cases be reduced from 4.5 to 0.2 grams.

COEFFICIENT OF EXPANSION OF ENGLISH CHINA CLAYS.

DETERMINATIONS of the coefficient of linear expansion of 17 English china clays which had been fired to seven different temperatures, were made by the Fizeau-Pulfrich method, which has been in use at the bureau for the measurement of small dilatations for a number of years. Because of the fine grained character of the clays and the fact that there was no admixture present, this method was considered to be the best for the purpose. The clays had been fired to cones 3, 5, 7, 11, 14, 18 and 23.

The thermal expansion curves obtained are practically linear in character over the range investigated, from room

temperature to 600° C. An interesting fact brought out in the investigation is the peculiar behavior noted in the linear expansion curves for all the clays that had been fired to cones 3, 5, and 7. In each case a "kink" was shown in the curve in the approximate range of 120 to 280° C., where the slope of the curve decreased considerably. This was probably caused by the presence of some water in the sample, but in just what form it was present it is impossible to say without further investigation of the matter. In each case a second determination resulted in a linear thermal expansion curve over the range from room temperature to 600° C., from which the mean coefficient of linear expansion was calculated. The calculated mean coefficients showed a minimum value of $.287 \times 10^{-5}$ and a maximum of $.501 \times 10^{-5}$, with an average value of $.387 \times 10^{-5}$.

From an examination of the results obtained, it would appear that the average tendency was for a gradual increase in the value of the mean coefficient of linear expansion from cone 3 to cone 11, followed by a gradual decrease in the values obtained for the clays fired at the higher temperatures.

MEASUREMENT OF pH IN NICKEL PLATING SOLUTIONS.

A CONFERENCE was held recently at the bureau of those persons who have coöperated in a research on the methods of measuring pH in nickel plating solutions. It was agreed that the hydrogen electrode measurements should be made the basis of all pH reports. Various methods of coördinating the results of colorimetric and electrometric measurements were discussed. It was recommended that the full report of the investigation be incorporated in a paper to be prepared at the bureau and to be presented at the fall meeting of the American Electrochemical Society.

Electricity Due to Air-blown Particles. P. E. SHAW. (*Proc. Roy. Soc.*, A 789.) "Electric charges due to mutual impact of dust or other particles arise in various ways: (*a*) electric dust- or sand-storms in the Tropics; (*b*) electric snow storms in the Antarctic; (*c*) electric flashes seen in the ejectamenta from volcanoes; and (*d*) electric charges, and possibly sparking, brought about by the raising of organic powders in certain industrial processes." It is the impact of like particles that produces such electrical charges, though it has been customary to hold unlike substances as necessary for the production of electricity by shock. A few years ago the author showed "that *identical* solid surfaces can charge one another by friction or impact, and, further, that this property of the surface changes as rubbing continues. It was there shown that such organic insulators as ebonite and celluloid yield considerable charges, whereas hard inorganic materials such as quartz, calcite and glass, produce smaller effects. When the 'like' solids meet in violent impact, not rubbing, the combined net charge is not nil, as might be expected according to Faraday's law of equal and opposite frictional charges, but finite, generally negative; so that the air surrounding the surfaces must attain an equal positive charge."

In the series of experiments here described measurements were made with an electroscope on the potential developed by blowing with a speed of 54 miles per hour successive charges of particles, each .15 c.c. in volume, through a tube into a vessel, both tube and vessel being lined with the same substance. When both were lined with copper the charge developed on the vessel decreased progressively from + .04 to − .27 electrostatic units as the driven particles were successively Cu, Fe, Brass, Zn. When both were lined with zinc a similar decrease from + .98 to + .14 E.S.U. was noted as the particles passed through the same change from Cu to Zn. The electrical charges on the solid particles are usually considerably larger than those on the air, but this is not so when copper meets copper or zinc meets zinc. Sand on sand causes very large charges on the grains, as well as on the sand-lined container.

The development of electricity is enhanced by having all surfaces clean, by raising the temperature of the blast and, by increasing the velocity of the blast. Even when the two surfaces brought into sharp contact are chemically alike electrical charges are produced by impact. G. F. S.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

A CONTRIBUTION TO THE PREPARATION OF STANDARD GELATIN.[1]

J. H. Hudson and S. E. Sheppard.

IT is recommended that the first standard gelatin prepared should be for scientific purposes; that is, it should be as near as possible a definite chemical compound, with physical properties equal to, or better than, the highest grade gelatin now obtainable. The question of its suitability for photographic or other industrial uses should not enter the question of its merits, as standards for a special purpose material can be prepared later.

Preferably the standard gelatin should be prepared from well-limed calfskin, and only the first extract taken. The finished product should contain not more than 0.05 per cent. ash and be at its isoelectric point of pH 4.7. More definite specifications for a standard gelatin should be decided upon only after several laboratories have completely tested a purified gelatin.

DYE TONING WITH SINGLE SOLUTIONS.[2]

J. I. Crabtree and C. E. Ives.

PREVIOUS experimenters employed single solution dye toning baths consisting essentially of a mixture of the mordanting bath and a basic dye, together with a protective agent; but since the basic dye invariably precipitated on standing, none of these formulas has been satisfactory.

A bath has been devised which contains no heavy metal

* Communicated by the Director.

[1] Communication No. 364 from the Kodak Research Laboratories and published in *Ind. Eng. Chem.* **21**: 263. 1929.

[2] Communication No. 372 from the Kodak Research Laboratories and published in *Amer. Phot.* **22**: 656. 1928; *Trans. Soc. Mot. Pict. Eng.* **12**: No. 36; *Brit. J. Phot.* **75**: 768. 1928.

but only potassium ferricyanide, acetic acid, a basic dye, and acetone. Acetone is a necessary solvent to maintain the dye in solution.

Nearly two hundred basic dyes were examined and ten were chosen as suitable for use in this bath. The optimum dye concentration varies with the dye used. A typical formula is the following:

Victoria green	0.4 gram
Acetone	100.0 c.c.
Potassium ferricyanide	1.0 gram
Acetic acid (glacial)	5.0 cc.
Water to make	1.0 liter.

The time of toning varies from five to fifteen minutes at 70° F., according to the depth of tone desired. The image does not intensify appreciably during toning so that it is possible to commence toning with images of normal photographic quality. This process of toning seems to have a less propensity to produce rack marks when toning by the rack and tank systems than the usual two-solution dye toning method.

Intermediate tones can be secured by using suitable mixtures of the dyes.

NOTES FROM THE U. S. BUREAU OF MINES.*

MICROSCOPIC STUDIES OF ORES RENDER REAL AID TO MINING INDUSTRY.

WHEN the microscopic study of ores was first undertaken at the Intermountain Experiment Station of the United States Bureau of Mines, Salt Lake City, Utah, the mining industry was, for the most part, totally unaware of the assistance that the microscopist could render the mill man in connection with the concentration of ores, the prevention of losses of values in mill tailings, etc. Gradually, however, as a result of the work that was done in the microscopic laboratory of the Intermountain Station, the value of such work was eventually realized by the industry. Last year one of the most progressive of the western mining companies installed a microscopic laboratory of its own. In doing so they first sent their ore-dressing engineer to the Intermountain Station so as to permit of his familiarizing himself with the Bureau's method of conducting its microscopic work. The Bureau was asked to make up a list of supplies and equipment that would be needed and after the laboratory had been installed the microscopist of the Intermountain Station assisted in putting it into operation. Now the mining companies of the district adjacent to Salt Lake City have arranged to install and maintain a service microscopic laboratory in the Department of Mining and Metallurgical Research of the University of Utah coöperating with the United States Bureau of Mines.

This laboratory will give its attention to those problems which are faced daily in plant operations and which involve intensive microscopic study of the various mill products including the ores which are treated. This work will be in the nature of fact-finding research and will serve as a basis for the application of theoretical consideration and study of problems whose importance is justified by the facts obtained. The scope of the work conducted in the laboratory will not be

* Published by permission of the Director, United States Bureau of Mines.

confined entirely to a study of ores and the problems encountered in milling, but will be extended to the field of geology. Microscopic study of rock formations and their relation to ore occurrence will form an important part of the laboratory work. There is also a field for microscopic study of smelter products, not only the slags which are produced under certain conditions, but of the materials entering the charge in the form of fluxes and ores.

Microscopic equipment of the latest and most refined character has been purchased and will offer facilities for using the most recent methods for conducting the various types of studies that will be made. Under this heading may be enumerated facilities for the study of extremely fine material, using dark field illumination. The various milling products examined will be subdivided into several minus 200-mesh products by means of elutriation, which has proven of great value in a study of ball mill practice now being conducted at the Intermountain Station. The study of sands or coarser material will be conducted through the agency of briquets prepared from acid-resisting substances and made under heat and hydraulic pressure.

LOW-FREEZING DYNAMITES.

THE thawing of frozen explosives was at one time a hazardous duty which fell to the lot of every user of explosives during the winter time. Many accidents occurred as a result of attempts to warm up the explosive before an open fire or on steam pipes or radiators. This hazard has almost been eliminated during the past 10 years by the development of low-freezing dynamites.

The physical characteristics of low-freezing dynamites have been the subject of a recent investigation by the Pittsburgh Experiment Station of the United States Bureau of Mines, Department of Commerce. Nitroglycerin, the explosive ingredient of dynamites, freezes easily, but the addition of nitropolyglycerin, ethylene glycol dinitrate, or certain nitro-substitution compounds to the nitroglycerin lowers the freezing point to such an extent that dynamites made with the mixture resist freezing under severe winter

conditions. The commercial use of ethylene glycol dinitrate was made possible recently by the development of manufacturing processes for the production of ethylene glycol on a large scale. The Bureau's investigation has shown that propulsive strength, rate of detonation, and sensitiveness are not adversely affected by the substitution. Investigation of the effect of the substitution on the safety of explosives of the permissible type has shown that the low-freezing explosives are equally safe for use in coal mines. The majority of permissible explosives are now of the low-freezing type.

TERMINOLOGY IN COAL RESEARCH.

An effort to clarify the meaning of various terms used in studying the constitution of coal has been made by representatives of the United States Bureau of Mines, Department of Commerce, and the British Safety in Mines Research Board in connection with the coöperative work being done by the two organizations with the object of finding methods of preventing or lessening accidents in coal mines. Because some of the mine-safety researches relate to spontaneous fires in mines and to the explosibility of coal dust in air, it has been necessary to study how coal is constituted and the characteristics of different coals of the same and different periods of formation, a study which in turn leads to the question of how coal is formed and the origin of the different portions of the coal. Since many investigators in different lands have described the constitution of coal and have used different terms in doing so, it is necessary in order to properly discuss the matter when comparing the coals of the different countries to have a full understanding of what the different terms mean in the different countries.

In Technical Paper 446, recently published by the Bureau of Mines, the authors, Reinhardt Thiessen and Wilfred Francis, have given particular attention to the terms "vitrain," "clarain," "durain," and "fusain," recently coined in England and to the terms "anthraxylon," and "attritus," evolved contemporaneously in America.

The conclusion is drawn that the English term "vitrain" has the same significance as the American term "anthraxylon."

These terms apply to those portions of coals of bituminous rank which are made up of brilliant bands with conchoidal fractures. These bright bands consist of woody portions of trees which were turned into coal during the accumulation of vegetable matter in the watery swamps of earlier coal-forming ages of the earth. The word "anthraxylon" is from the Greek anthrax (coal) and xylon (wood).

The English term "clarain" is considered to have the same meaning as the American term "attritus." These terms are used to describe those portions of coal consisting of dull bands which had their origin in a miscellaneous assortment of vegetable debris such as small splinters of wood, cellular structures, spores and pollen grains, cuticles and bark. The thin bright streaks in clarain are bright streaks of vitrain (anthraxylon) which cannot be readily separated from the duller portions. Inherently laminated, it breaks sharply with a small surface at the break.

The English term "durain" refers to a dull-band granular coal which has no counterpart in American coals. It is difficult to break, and surfaces are always granular or matt. It is largely composed of opaque matter and spores in varying proportions. The English term "fusain" is applied to what has been called "mineral charcoal" or "Mother of coal" in America. This dark, fibrous and powdery component is present universally in coal in small quantities.

The terms "anthraxylon," "attritus," and "fusain" may be used irrespective of the rank or geologic age of the coal. The terms "vitrain," "clarain," and "durain" should only be used for coals of bituminous rank.

The older terms of the Germans—namely, Glanzkohle and Mattkohle—have been used in various ways by different authors. Glanzkohle may have been used for what is now termed "vitrain," for clarain, or for both. Mattkohle is probably more nearly related to durain, although it may also have been used for the darker portions of clarain.

It is considered that this report should enable those who study coals, whether from a mine-accident standpoint or a fuel standpoint, to compare and understand the literature of the several countries on the subject of the constitution of coals.

NEW METHOD FOR CALCULATING TERRANE CORRECTION FOR GRAVITY GRADIENT IN GEOPHYSICAL PROSPECTING.

A new graphical method for calculating the terrane correction for gravity gradient in geophysical prospecting is outlined in Technical Paper 444, by Donald C. Barton, just issued by the Department of Commerce, through the United States Bureau of Mines. The paper gives a graphical method that, states the author, is as accurate as possible under the conditions of ordinary field surveying with the torsion balance, that is rapid, simple, and elastic, and that allows the observer to visualize readily the extent to which rugged topography will affect the gradient at his station. This graphical method is not meant to supersede the Eötvös or older Schweydar methods of calculating the terrane correction for the gradient but to supplement them where the terrane around the station has a relief of more than one-half meter above the level of the base of the instrument or more than several meters below it. The method given does not take into account the distinction made by Eötvös, Heiland, and others between the terrane correction for the zone within 100 meters and the cartographic correction for the topography further than 100 meters from the instrument; it can be used with ease to obtain the gradient terrane correction for all the topography further than 5 meters (5 feet if used with the Lancaster-Jones Shaw terrane formulæ).

TREATMENT OF ORES CONTAINING LEAD VANADATE OR LEAD MOLYBDATE.

Ores containing vanadium or molybdenum combined with lead are a minor source of these metals. A large number of complex minerals have been identified in such ores, but for metallurgical purposes the rare metals may be considered to occur as vanadinite and wulfenite, the vanadate and molybdate of lead respectively.

During periods of unusual demand domestic vanadinite and wulfenite have been produced and a small part of the present production of vanadium continues to come from foreign vanadinite.

The known vanadinite and wulfenite deposits in this country have not been of sufficient grade or size to interest the

large rare metal producers, and it is difficult for a small producer to find a market for such ores because they require a metallurgical treatment which is different from that used on the prevailing types of ore.

Vanadinite, wulfenite and related minerals are usually associated with other oxidized lead minerals, chiefly the carbonate. In some cases such deposits are worked for lead and the rare metal content of the ore is invariably lost because the smelter does not recover or pay for such metals.

Producers of such mixed ores should investigate the possibility of separating and refining the vanadium or molybdenum into marketable form. Due to their higher specific gravity and more compact crystal form, vanadinite and wulfenite travel higher on a concentrating table than the other lead minerals. A combination of selective mining and concentration may give a product of sufficient grade to justify refining operations. The Rare and Precious Metals Experiment Station of the United States Bureau of Mines in coöperation with the University of Nevada, Reno, Nevada, has prepared several papers dealing with the treatment of such concentrates.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, APRIL 17, 1929.

The regular stated monthly meeting of The Franklin Institute was called to order by the President, Mr. Nathan Hayward, at eight-twenty-three P.M.

The Secretary announced that the minutes of the last monthly meeting had been published in full in the April number of the Journal and moved that the minutes be approved as printed. This motion was unanimously adopted and the minutes were declared approved.

The Secretary stated the only item of business to come before the meeting was a report upon the membership acquisitions since the last meeting. He stated that two Resident and two Non-Resident members had been elected.

He announced with extreme regret the death of Dr. Samuel Rea, the former President of the Pennsylvania Railroad System and an Honorary Member and Franklin Medalist of the Institute.

There was no further business and the President asked Dr. Hobart A. Hare, as the representative of the Board of Directors of City Trusts, to assume charge of the meeting. Dr. Hare, as the representative of that Board, presented to Dr. Lee deForest of New York City, a member of The Franklin Institute, a John Scott Medal and premium of one thousand dollars. Dr Hare spoke as follows:

I am here to-night as a member of the Board of Directors of City Trusts, a Board which has the administration, among other funds, of that fund established in 1816 by John Scott of Edinburgh, Scotland. Evidently from such information as we have, John Scott was a great admirer of Benjamin Franklin. He devised to the City of Philadelphia as Trustee, the sum of $4000, and directed that the interest thereon should be used to reward ingenious men and women that make useful inventions, "the premium to be not more than $20," and a medal to be known as the "John Scott Medal," to be made of bronze and to bear the inscription "To the most deserving."

In the course of time the John Scott Medal Fund increased so largely that under an order from the court, the Board of Directors of City Trusts is now permitted to increase each award to a much greater sum.

The Board of Directors of City Trusts feeling that it would be wise to have expert evidence as to those who might be worthy for such an award, appointed a Commission consisting of Mr. Samuel Vauclain, President of the Baldwin Locomotive Works, Mr. Solomon M. Swaab, City Engineer of Philadelphia, Mr. Francis Shunk Brown, the Vice-President of the Board of City Trusts, and the speaker, the second Vice-President, to make recommendations as to those to whom the John Scott Medal and Premium should be given.

On their recommendation, the Board of Directors of City Trusts have voted that an award should be made to Dr. Lee DeForest, Electrical Engineer of New York City, for his invention of the audion which is used in radio and long distance communication, the more so as he is one of the pioneers in the development of wireless telegraphy and telephony in America. Indeed it may be said that his development of the audion made possible long distance telephoning and the

audion is, furthermore, the detector amplifier of the present radio apparatus. The device which Dr. DeForest developed acts as a valve which controls the flow of electrons from the hot cathode or filament to the anode or plate. It is, furthermore, interesting to note that his invention proved the key to the synchronization which has rendered possible the talking motion picture.

In order that the Board of Directors of City Trusts might be enabled to honor Dr. DeForest in the presence of those who also hold him in high regard, The Franklin Institute has been graciously pleased to permit this award to be made at this meeting.

Representing the Board of Directors of City Trusts, the administrator of the John Scott Medal Fund, I, therefore, take pleasure in presenting the medal and premium to Dr. DeForest.

Dr. deForest responded and made graceful expression of his recognition of the honor which had been done him and of his gratitude for the same. He spoke briefly in outline of the past development of the radio as based upon the audion, and ventured certain predictions as to the likely development of the future.

The President of the Institute then reassumed the Chair and presented as the speaker of the evening Dr. W. F. G. Swann, Director of the Bartol Research Foundation of The Franklin Institute. Dr. Swann made a "Report of the Year's Activities of the Bartol Research Foundation." He spoke as fully as time permitted of the many and important investigations which are being carried on in the Bartol Laboratories, and gave a convincing summary of the researches which have been completed or are in process at this time.

The meeting adjourned at ten-twenty P.M.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, April 3, 1929.*)

HALL OF THE INSTITUTE,
PHILADELPHIA, April 3, 1929.

DOCTOR THOMAS D. COPE *in the Chair.*

The following report was presented for final action:

No. 2906: Literature.

This report, recommending the award of the Louis Edward Levy Medal to Mr. L. J. R. Holst, Consulting Engineer and Vice President, of Brock and Weymouth, Inc., Philadelphia, for his paper on "Topography from the Air," published in the October, 1929 issue of the Journal of The Franklin Institute, was adopted.

The following report was presented for first reading:

No. 2905: Work of Doctor Chevalier Jackson.

This report recommended the award of the Elliott Cresson Medal to Doctor Chevalier Jackson, of Philadelphia, Pennsylvania, "In consideration of his researches on the mechanical principles involved in the removal of foreign bodies from the respiratory and food passages and of his designing of many instruments

for the purpose, and for his development of a technique for the use of these instruments."

On motion duly seconded it was voted to pass to the final reading, on the completion of which the recommendation was approved.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting, Board of Managers, April 10, 1929.*)

RESIDENT.

MR. HOWARD E. CORNELL, Naval Architect and Engineer, Public Ledger Building. For mailing: 1035 Public Ledger Building, Philadelphia, Pa.

MR EDWARD B. HALSEY, Radnor, Pa.

NON-RESIDENT.

DR. BERTRAM FEUER, Consulting Bacteriologist, 612 North Michigan Avenue, Chicago, Illinois.

MR. GEORGE N. SIEGER, Executive, Carboloy Company, Inc., 350 Madison Avenue, New York City.

CHANGES OF ADDRESS.

MR. WALTER H. DILKS, 8201 St. Martins Lane, Chestnut Hill, Philadelphia, Pa.

MR. MAURICE FELS, Garden Court, Forty-seventh and Pine Streets, C 510, Philadelphia, Pa.

MR. H. ARTHUR GROSSCUP, 315 Pearl Street, Hartford, Connecticut.

DR. JOSEPH S. HEPBURN, Hahnemann Medical College, 235 North Fifteenth Street, Philadelphia, Pa.

MR. NATHAN M. LOWER, Lower Stoker Company, 932 North Lincoln Avenue, N. S., Pittsburgh, Pa.

DR. WALTER A. MACNAIR, Bell Telephone Laboratories, Inc., 463 West Street, New York City.

MR. H. W. MAJOR, 602 Heartwell Building, Long Beach, California.

MR. WILLIAM CLARKE MASON, 2107 Fidelity–Philadelphia Trust Building, Philadelphia, Pa.

MR. CHARLES H. NORDHAUS, 3920 Cullom Avenue, Irving Park Station, Chicago, Illinois.

MR. FRANK H. SAUER, 129 Manor Avenue, Oaklyn, New Jersey.

MR. ARTHUR W. THOMPSON, Dunwoddie, West Chestnut Avenue, Chestnut Hill, Philadelphia, Pa.

MR. ROBERT L. WOOD, Bateman Brothers, Inc., Malvern, Pa.

NECROLOGY

Dr. Samuel Rea, Philadelphia, Pa.

LIBRARY NOTES.

RECENT ADDITIONS.

American Medical Association. New and Non-Official Remedies. 1928.

American Pharmaceutical Association. Year Book 1926. Volume 15. 1928.

BACON, ROGER. The Opus Majus of Roger Bacon: a Translation by Robert Belle Burke. Two volumes. 1928.

BRODETSKY, S. Sir Isaac Newton: a brief Account of His Life and Work. 1928.

CREIGHTON, H. JERMAIN. Principles and Applications of Electrochemistry. Volume I, Principles. Second edition, revised and enlarged. 1928.

MAILHE, A. Les Combustibles Liquides Artificiels. 1929.

MOYER, JAMES AMBROSE. Steam Turbines. Sixth edition, revised and enlarged. 1929.

National Advisory Committee for Aeronautics. Bibliography of Aeronautics, 1926 and 1927. Two volumes. 1928.

NEWBOLD, WILLIAM ROMAINE. The Cipher of Roger Bacon. Edited with foreword and notes by Roland G. Kent. 1928.

PAGE, LEIGH. Introduction to Theoretical Physics. 1928.

Philadelphia College of Pharmacy and Science. Popular Science Talks. Volumes 3–6. No date.

RAWLINS, F. I. G., AND A. M. TAYLOR. Infra-Red Analysis of Molecular Structure. 1929.

U. S. Patent Office. Index of Patents, 1928. 1929.

WIEN, W., AND F. HARMS, editors. Handbuch der Experimentalphysik, Band 20, 1 Teil: Physiologische Optik von A. Kŏnig. 1929.

BOOK REVIEWS.

THE BIOCHEMISTRY OF THE AMINO ACIDS. By H. H. Mitchell, Professor of Animal Nutrition, College of Agriculture, University of Illinois, and T. S. Hamilton, Associate in Animal Nutrition, College of Agriculture, University of Illinois. 619 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1929. Price $9.50.

This is one of the many monographs prepared under the auspices of the American Chemical Society. This series has been of great value to chemists because while each volume is devoted to a special field and often to a somewhat narrow field, yet the series has been extended to cover a very large part of chemistry both pure and applied. "Biochemistry" is a comparatively new term, but an expansive one, and relating to a very important and interesting department of applied science. The particular field of this book shows the high specialization of the modern science for it relates to only one line of compounds. These compounds have an intimate relation with protein chemistry and of course for that reason with the higher problems of animal nutrition.

The field of animal biochemistry and the physiology of nutrition have, as the authors remark, experienced a very rapid expansion in the last score of

years and like most other expanding fields of science the rate of progress is itself accelerating. In such rapid development mistakes are apt to occur, results may be reported without due checking of interfering conditions, and indeed two careful investigators may by reason of slightly different technic get different results, and impurities of reagents may be overlooked. In a progressive science of this type much material becomes out of date often in a few years, and the author of a volume presenting the existing state of a science has to sift carefully the material that is offered. It is not possible for the author to verify all the statements that he records; he must use his judgment in many cases, and even the best judgment may go astray. The authors point out that the science of nutrition so rapidly expanding is suffering from the complacency of investigators, arising largely from the fact that definite information seems to be acquired comparatively easy.

This review of the present state of knowledge of the amino-acids and their function in animal life has been presented by the authors after careful consideration. They are not unaware of the danger of being too positive as to the data over a wide field, only a limited portion of which they have themselves traversed.

The book deals with principles and not to any appreciable extent with methods. It is therefore, a treatise on the subject rather than a laboratory guide. The bulk is limited to recent work, no attempt being made to deal in detail with the earlier story of the subject. This is quite correct, for the purpose of these monographs is to present present day knowledge in the field. The book exhibits the usual excellence of make-up that characterizes the publications of the Chemical Catalog Company and is a welcome addition to the important field of physiological chemistry, and gratifying as a product of work from the Middle West.

HENRY LEFFMANN.

GAS CHEMISTS' HANDBOOK. January 1, 1929. Revised by the Committee on Analysis, Tests and Editing Gas Chemists' Handbook. A. F. Kunberger, Chairman, W. H. Fulweiler, C. A. Lunn, N. F. Prince and C. C. Tutweiler. Third Edition, 795 pages, 131 figures, 8vo. Published by the American Gas Association, 420 Lexington Avenue, New York. Price $7.00.

The degree to which advancement and refinement can take place in testing and analytical technique is exemplified in the new edition of the Gas Chemists' handbook. This third edition which came from the press just recently has been thoroughly revised in many of its sections while others have been rewritten in their entirety.

The subject matter has been divided into four main parts or chapters under the headings Raw Materials, Products of Gas Manufacture, Impurities in Gas and Miscellaneous. An excellent feature, for which the members of the committee are to be commended highly, is the adoption for many materials the methods of analysis already accepted as standards by the American Society for Testing Materials. These methods in addition to those developed by the sub-committees all have met the approval of the Chemical Committee of the American Gas Association.

Chapter one on raw materials is divided into three parts—coal and coke, gas oil, and purification material. Methods of sampling the material are de-

scribed in detail. Similarly great care has been taken to include all the tests of practical value and to describe them with a clarity and directness which will leave no uncertainty in the mind of the worker. The greater portion of Chapter two, Products of Gas Manufacture, is given to the various methods of analyzing gases. The remainder of the chapter is taken up with Light Oils, Ammonia, Tar and Cyanogen. The principal methods of gas analysis are described with great care and the whole subject has been brought up to date by the writers, Yant and Fieldner of the Bureau of Mines. Special attention has been paid to the methods for determining small amounts of carbon monoxide, oxygen and olefines. This includes a description of the application of the thermal-conductivity method of gas analysis to the testing of gas appliances. Various types of apparatus for the determination of density, heating value and dew point are described and include descriptions of the operations of the Ranerex Density Recorder, the Thomas calorimeter and the Tutweiler hygrometer. Chapter three on Impurities in Gas describes hydrogen sulfide tests which afford quantitative works control and also has included the latest methods used in the determination of naphthalene in gas. A description of the Conductivity Bridge Method for naphthalene has been added. Under the heading, Miscellaneous, Chapter four, will be found methods for the analysis of water, paint and paint materials, lubricants; solder, bearing metals, brass and bronze; pipe deposits, refractories, cement, lime and ferrous metals. The methods of water analysis are those adopted by the American Public Health Association. The appendix consists of a series of tables which the gas chemist will find to be of immense value as an aid to calculations and a convenient source of accurate information. The table of constants for certain gases and vapors has been carefully revised and brought up to date by the chairman, A. F. Kunberger.

This recent issue of the Handbook is a marked improvement over the two previous editions. Apparently the committee has spared neither time nor trouble in order to give this book a high standard of quality evidenced by its accuracy and completeness of detail.

T. K. CLEVELAND.

INTRODUCTION TO THEORETICAL PHYSICS. By Leigh Page, Ph.D., Professor of Mathematical Physics in Yale University. x-587 pages, 201 figures. New York. D. Van Nostrand Company, 1928. Price $6.50.

During the decade just passed a relatively large number of books have been published on the subject of physics. Many of these books deal with the study of physics in a general way and possess a high standard of excellence in regard to thoroughness, clarity and a logical presentation of its subject matter. This "Introduction to Theoretical Physics" is no exception to the rule. The author, a professor of mathematical physics, has written accordingly. The various physical laws describing conditions of the universe are here expressed in the form of mathematical equations which have been developed step by step from differentials representing the experimentally observed conditions and facts.

The first part of the book contains an introduction on Vector Analysis. Sufficient attention and detail has been accorded the subject so that the reader may follow intelligently the application of vectors in subsequent chapters.

Part One of the book deals with the dynamics of particles, of rigid bodies, and of deformable bodies as well as containing a chapter covering the subject in its more advanced phases. In this section may be found a very comprehensive treatment of the motions of tops, gyroscopes, pendulums and falling bodies. Part Two on hydrodynamics is a treatment of the laws governing the motions of and in perfect and viscous fluids. Part Three on thermodynamics should be of particular interest to physical chemists and chemical engineers. The section contains a comprehensive exposition of the laws of classical thermodynamics and of the kinetic theory of gases. Part Four on electromagnetism is concerned chiefly with relations developed from the experimental laws of Coulomb, Ampère and Faraday. In the chapter on electromagnetic theory may be found sections upon radiation pressure, principle of relativity, and various effects related to spectra. Part Five on optics and spectroscopy deals with that section of physical science attracting most attention at the present time. A chapter on geometrical optics is followed by one on physical optics which deals with the properties of gratings and interferometers. The final chapter on the origin of spectra lays particular emphasis upon the mathematical treatment of the subject and is not given to the elaboration of the various possible corollaries pertaining to the more recent theories.

The work of compilation of such a book must have been indeed tedious. The unstinted use of mathematical equations should make the book immensely valuable to students of research and instructors in physics. The instructive value of the book has been greatly enriched by the introduction of practical problems involving the application of the principles elaborated.

T. K. CLEVELAND.

THE SPECTROSCOPY OF THE EXTREME ULTRA-VIOLET. By Theodore Lyman, Ph.D., Hollis Professor of Natural Philosophy, Emeritus, in Harvard University. Second edition, vii–160 pages, illustrations, 8vo, cloth. New York, Longmans, Green and Company, 1928. Price, $3.75.

Always a subject of prime importance in modern physical science, radiation has come to play a capital rôle in its relation to matter, and especially in recent times physicists have gathered an enormous amount of precise data on the visible, infra-red and ultra-violet parts of the spectrum. Research in the ultra-violet has been particularly prolific in results of value but only by overcoming unusual difficulties entailed in dealing with these short waves. Progress was slow in the advancement of knowledge of the ultra-violet region in the early days of spectroscopy with occasional rapid strides, notably by Becquerel and by Stokes and later by Mascart, followed by the classic research of Ångström and the brilliant invention by Rowland of the concave grating. During the period terminating with the work of Cornu the causes of limitation of the spectrum by absorption were made clear, and a little later Schumann succeeded in overcoming these difficulties and extended the known spectrum wave-length to 1200. It is in this latter region that Doctor Lyman's researches have been recorded, described and analyzed in this volume.

Says the author "the title of the book might well have been, 'Spectroscopy of the Schumann region' for it deals with that end of the ultra-violet spectrum where

the absorption of air plays the determining rôle. The present title is chosen however because a more extended field is necessary in order to trace the beginnings of these phenomena which becomes pronounced as the region beyond wave-length 2000 is explored. Thus the absorption of the air begins to manifest itself in the ordinary ultra-violet, though it only becomes critical near wave-length 2000, and the absorption of many solids, usually considered transparent in the ultra-violet begins to suffer a modification even before the region of shortest wave-lengths is reached. The book is, therefore, divided into two parts. The first and shorter portion deals with that part of the spectrum lying between wave-length 4000 and 2000; this is the region usually referred to as the ultra-violet. The second and longer portion treats the spectrum on the more refrangible side of wave-length 2000; this is the extreme ultra-violet or Schumann region."

Preceded by a brief historical survey, Part I includes data on photometry in the ultra-violet, on the absorption of optical systems, and on the absorption of gases. Part II deals with apparatus and methods of investigation in the extreme ultra-violet, specific data on absorption and reflection in the extreme ultra-violet, emission spectra of various substances, radiations from gases and solids in the extreme ultra-violet, photo-electric phenomena and the extension of the spectrum. At the end of the volume are the author's early measurements of the spectra of hydrogen and carbon monoxide and other measurements collected from various sources of the spectra of carbon, nitrogen, oxygen and aluminium. A copious bibliography alphabetically arranged by authors, a list of the papers of V. Schumann and a description of his methods of preparing dry plates conclude the volume. Subject and author indexes are provided. A second edition of this important work which now records the approach of the extreme ultra-violet region into the domain of soft X-rays with its many details of recent research and technique is a welcome addition to the literature of leading and original work on spectroscopy.

L. E. P.

THE INDUSTRIAL DEVELOPMENT OF SEARLES LAKE BRINES WITH EQUILIBRIUM DATA. By John E. Teeple, Ph.D., American Chemical Society Monograph Series. 182 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1929. Price, $3.

The outbreak of the World War, with its establishment of the strict British blockade, gave the United States a severe lesson as to the danger of implicit reliance on other lands for materials essential to its manifold activities. The reaction to the failure to secure the coal-tar dyes may have been partly sentimental, but the interruption of the potash supply struck at the heart of one of our great industries. There was an immediate search for sources of this important fertilizer. The price rose enormously, a condition that was in itself a strong incentive to research. Among the sources that were made available was the content of the brines of Searles Lake in California, the principal solid ingredients being salt, sodium carbonate, sodium sulphate, borax and potassium sulphate, the latter being closely associated with sodium sulphate. The lake, much larger in ancient times, now covers about twelve square miles, the several salts having been deposited in considerable quantity in its shallow basin and existing in strong solution in the water.

The present volume, one of the long series of monographs by the American Chemical Society, is devoted to the history of the utilization of the Searles Lake products, especially borax and potash. As might be expected, this industry, developed with rapidity and under severe stress, has some energetic features. Many difficulties were encountered, but in the early period of the operation, the high price of the product enabled satisfactory results to be obtained, and Searles Lake potash, with potash from several other hitherto overlooked sources, became important supplies to American agriculturists. With the signing of the Armistice, the foreign supplies were again available. Interested parties, especially representatives of the foreign firms, importers and their accessory agents were loud in their advocacy of the view that no effort should be made in America to establish a potash industry.

Dr. Teeple's book is not a descriptive technology, but a summary of a large amount of scientific data accumulated in the laboratory of the plants of the American Potash and Chemical Corporation, at Trona, utilizing the Searles Lake brines. Commendation is due to the Company for permitting the publication of these data. The physical chemistry of the problem is very thoroughly set forth. The work of supplying from American sources two important chemicals, potash salts and borax, in competition with world supply has been undertaken and after much struggle is successful although only recently established. The book also gives a succinct account of the application of research, technology and common sense to the problem. The motive has been not only to set forth scientific data of moment but to show the peculiar attitude that has been manifested towards the effort to establish an American industry as noted above. Few things are more aggravating than loud and dogmatic assertions that something cannot be done. We are reminded by this thought that Lord Kelvin and Simon Newcomb strongly deprecated Langley's efforts towards securing a heavier-than-air flying machine. The man who is explaining that a thing cannot be done, is often interrupted by somebody doing it. Dr. Teeple writes in a forceful style and his thorough familiarty with all phases of the work to which the book is devoted will place it in the front rank of contributions in a very important field of American industry.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 298. Effect of Variation of Chord and Span of Ailerons on Rolling and Yawing Moments in Level Flight, by R. H. Heald and D. H. Strother. 19 pages, illustrations, quarto. Washington, Government Printing Office, 1929. Price ten cents.

This report presents the results of an investigation of the rolling and yawing moments due to ailerons of various chords and spans on two airfoils having the Clark Y and U. S. A. 27 wing sections. Some attention is devoted to a study of the effect of scale on rolling and yawing moments and to the effect of slightly rounding the wing tips.

The results apply to level flight with the wing chord set at an angle of attack of $+4°$ and to conditions of zero pitch, zero yaw, and zero roll of the airplane. It is planned later to extend the investigation to other attitudes for monoplane and biplane combinations.

The work was conducted in the 10-foot wind tunnel of the Bureau of Standards on models of 60-inch span and 10-inch chord.

Report No. 302. Full Scale Tests on a Thin Metal Propeller at Various Tip Speeds, by Fred W. Weick. 14 pages, illustrations, quarto. Washington, Government Printing Office, 1928. Price ten cents.

The investigation described in this report was made in order to determine the effect of tip speed on the characteristics of a thin-bladed metal propeller. The propeller was mounted on a VE-7 airplane with a 180-HP. E-2 engine, and tested in the 20-foot propeller research tunnel of the National Advisory Committee for Aeronautics. It was found that the effect of tip speed on the propulsive efficiency was negligible within the range of the tests, which was from 600 to 1000 ft. per sec. (about 0.5 to 0.9 the velocity of sound in air).

Report No. 305. The Gaseous Explosive Reaction. A Study of the Kinetics of Composite Fuels, by F. W. Stevens. 18 pages, illustrations, quarto. Washington, Government Printing Office, 1929. Price fifteen cents.

This report deals with the results of a series of studies of the kinetics of gaseous explosive reactions where the fuel under observation, instead of being a simple gas, is a known mixture of simple gases. In the practical application of the gaseous explosive reaction as a source of power in the gas engine, the fuels employed are composite, with characteristics that are apt to be due to the characteristics of their components and hence may be somewhat complex. The simplest problem that could be proposed in an investigation either of the thermodynamics or kinetics of the gaseous explosive reaction of a composite fuel would seem to be a separate study of the reaction characteristics of each component of the fuel and then a study of the reaction characteristics of the various known mixtures of those components forming composite fuels more and more complex. This is the order followed in the simple studies herein described. R.

PUBLICATIONS RECEIVED.

Gas Chemists' Handbook, January 1, 1929. Revised by the Committee on Analysis; Tests and Editing Gas Chemists' Handbook. Third edition, 795 pages, illustrations, 8vo. New York, American Gas Association, no date, price $7.00.

Theoretical Mechanics. An introduction to mathematical physics by Joseph Sweetman Ames and Francis D. Murnaghan. 462 pages, illustrations, 8vo. Boston, Ginn and Company, 1929, price $5.00.

Encyclopédie Léaute. Les automobiles sans Pétrole. Les Combustibles liquid artificiels par A. Mailhe. 281 pages, 12mo. Paris, Gauthier-Villars et Cie, 1929, price 30 francs.

Infra-red Analysis of Molecular Structure, by F. I. G. Rawlins, M.Sc., and A. M. Taylor, M.A. 176 pages, illustrations, 8vo. Cambridge, University Press, New York, The Macmillan Company, 1929.

Ontario Department of Mines. Thirty-seventh annual report, being volume 37, part II, 1928. Kirkland Lake Gold Area (a detailed study of the Central Zone and vicinity) by E. W. Todd. Text, maps, plates, 2 vols., 8vo. Toronto, King's printer, 1928.

Operational Circuit Analysis, by Vannevar Bush, Eng.D., with an appendix by Norbert Wiener, Ph.D. 392 pages, illustrations, 12mo. New York, John Wiley & Sons, Inc., 1929, price $4.50.

The Biochemistry of the Amino Acids, by H. H. Mitchell and T. S. Hamilton. American Chemical Society Monograph Series. 619 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1929, price $9.50.

National Advisory Committee for Aeronautics. Technical Notes No. 304. Corrosion embrittlement of duralumin. V. Results of weather exposure tests by Henry S. Rawdon, Bureau of Standards. 26 pages, illustrations, quarto. Washington, Committee, 1929.

U. S. Bureau of Standards. Research Paper No. 45. Apparatus and methods for the separation, identification, and determination of the chemical constituents of petroleum by Edward W. Washburn, Johannes H. Bruun and Mildred M. Hicks. 22 pages, illustrations, 8vo. Washington, Government Printing Office, 1929, price ten cents.

U. S. Bureau of Standards. Recombination spectra of ions and electrons in cæsium and helium by F. L. Mohler and C. Boeckner. 12 pages, illustrations, 8vo. Washington, Government Printing Office, 1929, price five cents.

CURRENT TOPICS

Erosion by Water-hammer. S. S. Cook. (*Proc. Roy. Soc.*, A 783.) The matters discussed in this paper are connected with the pitting of condenser tubes and the erosion of propeller blades and of steam turbine blades. It is not always easy to distinguish erosion from corrosion. Erosion may furnish conditions favorable to corrosion by removing a surface layer or protecting scale or by carrying away the products of corrosion. "In many cases the reason for attributing the action to corrosion rather than to erosion is merely that the mechanical nature of the cause is not sufficiently apparent, through a failure to recognise the remarkable ability of water and other nearly incompressible fluids under certain circumstances, to produce momentary pressures far in excess of the yield-point strength of ordinary materials."

When a spherical cavity in an incompressible liquid suddenly collapses very high pressures are caused. Such a case may arise when a stream of water flowing into a tube is suddenly shut off. The momentum of the liquid would tend to keep it moving but with the formation of cavities that would collapse a moment later. The author calculates the pressure developed in a suppositious case and finds it to be 65 tons per sq. in. What takes place in the water-hammer is this. "If a moving column of water is suddenly arrested by a fixed surface, without any interposing gas to cushion the blow, there is a sudden arrest of the front layer of the impinging column. The pressure generated by the blow in such a case is only limited by the fact that both solids and fluids possess a slight degree of compressibility, so that the velocity energy of the front layer of the column is converted on impact into potential energy. It should be noted, too, that the water-hammer pressure induced by a suddenly arrested column of water is independent of the length of the column. It follows that drops of water, however minute, will at the first moment of impact produce the same water-hammer effect as large volumes of water, the only difference being in the area of attack and the duration. The duration will depend upon the length of the column, being the time required for the shock wave to travel to the end of the column and back again to the surface of impact. For example, if the column is 1 meter in length the pressure endures for about 1/700 part of a sec." In general the pressure due to the sudden stopping of water is much greater than that caused by the impact of a jet of the same liquid moving with the same velocity. It is only when the speed of the jet attains the velocity of sound in the liquid that the pressures become equal.

The author calculates the pressure due to impact in a steam turbine between the blades and drops of water in a high vacuum. On blades moving with a speed of 120 meters per sec. it amounts to 12 tons per sq. in., and for 300 m./sec. it is 30 tons per sq. in. "so that it will be seen to be of the same order as the yield-point of materials usually employed." Turbine blades 4 inches long were mounted on a shaft and rotated within a cylindrical casing. At two diametrically opposite places jets of water were sprayed across the moving blades. The blades were rotated for 18½ hours at 8,800 revolutions per min. The speed of the impact of the water was 140 meters per sec. at the part of the blades nearest to the axis and 233 m./sec. at the outermost part. The respective pressures were 12.4 and 20.7 tons per sq. in. The results were as follows:

Material of Blade.	Elastic Limit Tons/Sq. in.	Condition After Test.
"Hecla A.T.V." steel	51	Unattacked
Tungsten steel	40	Rusted and slightly eroded
"Staybrite" steel	16	Considerably eroded
Monel metal	18	Considerably eroded
Mild steel	16	Etched as by sand blast

G. F. S.

Experiments on the Diffraction of Cathode Rays. G. P. THOMSON. **The Diffraction of Cathode Rays by Thin Celluloid Films.** A. REID. **The Diffraction of Cathode Rays by Thin Films of Copper, Silver and Tin.** R. IRONSIDE. (*Proc. Roy. Soc.*, A 783.) According to de Broglie's theory of mechanics a particle in motion acts as a group of waves whose velocity and wave-length depend upon the mass and velocity of the particle. If the particles are electrons that have the velocity acquired by falling through a difference of potential ranging from 10,000 to 40,000 volts the corresponding wave-lengths would vary from 1.22×10^{-9} to $.66 \times 10^{-9}$ cms. Hard X-rays have such wave-lengths. Hence it was a fair supposition that crystals would accord the same treatment to both X-rays and to electrons. On page 417 of the September 1928 issue of this JOURNAL is published an account of experiments made by G. P. Thomson, son of Sir J. J. Thomson and Professor of Natural Philosophy in the University of Aberdeen, showing that the crystals in thin films of metal and of celluloid actually follow the predicted course. This group of three papers report further work done upon the same subject in the Aberdonian laboratory.

Prof. Thomson states that improved methods have produced better agreement between the quantitative results derived from

X-ray measurements and those based on the diffraction of electrons. After considerable difficulty he succeeded in extending his method to platinum films with which he obtained diffraction effects in agreement with theory. A beam of electrons fell at right angles upon the film and after passing through was received on a photographic plate. Upon development this showed a central image surrounded by rings due to diffraction.

An approximately uniform magnetic field was applied to the electrons issuing from the film. Both the central image and the diffraction pattern were deflected through 3 cm., this distance being dependant upon the electron velocity. Measurements show that there is so little difference between the distances through which the central and the diffracted rays are displaced that "the speed of the diffracted rays is certainly the same as that of the main beam to less than 1 per cent." Since a magnetic field would not deflect light waves the fact that deflection takes place is evidence, were evidence needed, that the diffraction pattern is not produced by light. "The question of the number of waves accompanying an electron is of great theoretical importance. The large resolving power seems definitely to show that the waves extend with appreciable amplitude over a distance at least of the order 50×10^{-8}, which makes the wave system of the free electron larger than an atom. The only way of reconciling the experiments with an electron, the amplitude of whose waves is concentrated in a small region, seems to be to suppose that the different electrons in the beam influence each other, so as to produce a coherent wave."

From the fact that the speed of electron waves increases with the wave-length an interesting state of affairs results. Even in a vacuum the waves do not stay together but the longest waves outrun the rest. Unless only waves of one wave-length are present the train will grow longer as the distance separating the long from the short waves becomes progressively greater.

Reid working with films of celluloid obtained results that confirm previous investigations of this material. To get thin films he dissolved celluloid in amyl acetate and placed a little of the solution upon the surface of water. When the solvent has disappeared a film of celluloid about 500 Å. U. thick remains. Ironside had little difficulty in getting silver films sufficiently thin. Copper presented more of a problem. The thinnest possible leaf was dissolved in part by floating it on nitric acid. It was impossible to get tin foil as thin as was desired for the experiment, so that the results were rather poor. The length of the lattice constants of these three metals determined by electron diffraction diverged only one or two per cent. from that derived from X-ray measurements. G. F. S.

Geophysical Methods of Prospecting, with Special Reference to Magnetic, Radioactive, and Electric Methods. C. A. HEILAND. (*Ter. Mag.*, Sept., 1928.) This is an abstract of a paper presented to the American Geophysical Union, April, 1928. It contains a valuable tabulation of the various geophysical methods of prospecting. Two general groups are recognized. "The first group comprises methods (for example, gravitational) by which direct effects of subterranean inhomogeneities are observed. The second group consists of procedures (for example, seismic, magnetic radioactive, and electric) whereby artificial fields of force are produced and their distortion by subterranean bodies of different physical properties is measured." In the first group we find gravitational methods, where the pendulum is used to detect large structural features and where the torsion balance, giving gravity gradients and curvature values, is applied to locating ore deposits, salt domes and the relief of buried terrain; natural earth-currents used especially for sulphide ores; thermic action, where the thermal gradient is measured. This method is used for mineral-oil structures and ores in wells and shafts; magnetic and radioactive methods, both of which will be discussed later in this abstract. In the second group are collected methods depending on reaction to elastic waves whether of acoustic or seismic nature, applied to the location of ores; on reaction to wireless waves, used for sulphide ores and brine accumulations; on reaction to electric currents discussed below.

The Magnetic Method.—This, perhaps the oldest geophysical method, depends on different minerals and formations possessing different magnetic permeabilities. It serves to locate deposits of iron ore and is valuable in oil geology, if the oilbearing structures go with igneous rocks, for these always contain magnetite. Gold and platinum can be located in placer deposits since they are accompanied by magnetite. Even non-magnetic deposits can be detected provided they are associated with magnetic formations or are as strongly diamagnetic as salt-domes. For coarse work for ore bodies the dip needle and the magnetometer are sufficient. For the search for oil vertical and horizontal field balances are chiefly relied upon. The theory of the effect of subterranean bodies on magnetic quantities has been investigated by at least fourteen writers.

Radioactive Methods.—Samples of earth are taken at intervals and the radioactivity is determined or the radioactivity of air accumulating in holes made in the earth some time previously is measured or measurements are made with an ionization chamber without bottom placed directly on the ground and moved from spot to spot or the radiation from the soil is measured at intervals with a shielded chamber or, finally and most commonly, an ionization

chamber mounted on a tripod is moved from place to place, air from a hole in the surface of the ground is pumped into it and its radioactivity is measured.

This general method lends itself to the detection not alone of radioactive minerals but of faults and dykes as well. Faults show enhanced radioactivity probably because they facilitate the circulation of radioactive air and water, and their location is desirable when dams are projected. In Europe this method has succeeded in finding faults and dykes.

Electric Methods.—For their application these depend on the formations sought having a different electric conductivity from their surroundings. Ore bodies are good conductors especially sulphides. Electric prospecting for ore has proved to be quite successful in Canada, Upper Michigan, Newfoundland, Arizona and New Mexico. It is, however, applied to oil geology also. Salt domes that accompany oil are insulating in character and besides this conclusions as to general structure can be drawn from a study of the distribution of electrical conductivity. The method is not as useful for oil as for ore. There is a great variety of these methods and the literature is considerable. G. F. S.

Ozone in the Northern and Southern Hemispheres. F. E. FOWLE. (*Ter. Mag.*, Sept., 1928.) It is easier to measure the radiation reaching the earth from the sun when the localities of the observations are in the southern hemisphere (Calama and Montezuma, Chile) than when they are in the northern hemisphere (Mt. Wilson, Harqua Hala, Table Mountain). The question is raised whether this may not be due to a difference between the amount of ozone "which spoils the apparently excellent skies of such a station as Table Mountain, California." Ozone is formed from oxygen by the action of a range of short wave-lengths in the solar radiation lying in the ultraviolet. It is decomposed by the action of group of longer wave-lengths likewise in the same region of the spectrum. "Hence, a layer of ozone might exist from this cause high up in the atmosphere where the former effect preponderated. Lower down as the energy of the shorter wave-lengths of the sun's energy became more rapidly weakened than the longer, a place would be reached where the decomposition effect would exceed the generation, and no ozone would be found." From a study, made in the laboratory, of the absorption of solar radiation by ozone one can calculate the amount of this substance needed to produce the absorption due to it that is observed in the solar spectrum, but only about one-twentieth of this amount is found in the air at sea level or at the top of Mt. Blanc. This was confirmed by a study of the trans-

mission through air near the earth of a certain mercury line. It was transmitted through 6.5 kilometers of air. This would have been quite impossible had all the ozone, indicated as present in the entire atmosphere, been equally distributed throughout the whole mass of the air. "The ozone causing the absorption in the solar spectrum should therefore be found at a considerable altitude, and Cabannes and Dufay have estimated this altitude at about 50 kilometers."

From a daily study of an absorption band in the solar spectrum that is caused by ozone the author has derived the absorption by this gas in the atmosphere. This was done for the period from Dec., 1925, to Dec., 1927, and for Table Mountain, Cal., and Montezuma, Chile. "There is a comparatively small and apparently constant amount of ozone above the Chilean solar station. Above Table Mountain it exists in an amount capable of exercising a considerable disturbing effect upon the incoming solar radiation. There is above Table Mountain a distinct seasonal variation for the two years shown, the absorption being greatest in the early months of the year, reaching a minimum along the early part of November for the two years stated. The amount of ozone above Table Mountain shows some relationship between the magnetic character of the day, the total spottedness (of the sun), and a very decided relationship with the number of flocculi over the whole disc."

Attention is directed to the importance of ozone for three branches of science: (1) To meteorology because of its effect upon solar radiation by absorbing this and thus keeping it from reaching the surface of the earth and because of its acting as a blanket to prevent the escape of infra-red radiation coming from the earth itself; (2) To astrophysics, and (3) To terrestrial magnetism and atmospheric electricity, as the ozone in the upper regions of the atmosphere is equal to a conducting layer there that moves about the magnetic earth with the motion of the sun. G. F. S.

Production and Properties of High-frequency Radiation. SIR E. RUTHERFORD. (*Nature*, Dec. 8, 1928.) The expression 'a quantum of radiation' has grown to be quite familiar to readers of modern physics. It indicates a definite amount of radiation-energy that is emitted and absorbed as an entity. It is the modern counterpart of Newton's corpuscle of light. Radiations of different wave-lengths have different quanta. The shorter the wave-length the larger the energy of the quantum, for the energy of a quantum is the product of Planck's constant h and the frequency of the particular radiation. "It is very convenient to express the energy of a quantum not in ergs but in terms of a potential difference in volts, through which an electron must fall to acquire an equal

energy. Expressed in this way, the energy of a quantum of green light corresponds to 2 electron-volts, or 2 volts for brevity. Before the advent of X-rays the highest frequencies examined were confined to the ultraviolet part of the light spectrum, corresponding to less than 10 volts. Following the discovery of X-rays and the application of methods for determining their frequency, we have been enabled to study radiations over a wide range of individual energy, varying from a few hundred volts to 300,000 volts or more." When electrons impinge upon matter X-ray radiation of many frequencies is produced. The faster the electrons travel the greater is the maximum frequency in the resulting group of radiations produced. It seems that there is no limit to the frequency attainable except that set by our ability to impart velocity to the bombarding electrons. "In some recent experiments in the Institute of Technology, Pasadena, about a million volts have been successfully applied for a short time to a suitably designed X-ray tube. It is stated that the X-rays obtained were of such intense and penetrating power that they could easily be observed by the luminosity on a phosphorescent screen 100 feet away." So far the laboratory cannot yield radiation with the penetrating power of the gamma rays spontaneously emitted in radioactive transformations. The energy of their quanta corresponds to 3 or 4 million volts, and the rays coming from weakly radioactive potassium seem to have even greater quanta.

From the equivalence of mass and energy it is possible to calculate the frequency of the energy emitted in some simple atomic changes, but experimental verification is difficult because of the enormous amount of energy associated with a gram of matter. "The atom of uranium of mass about 238, after successive transformations involving the loss of 8 α-particles, changes into an isotope of lead of mass about 206. It is to be anticipated that, if the methods of positive ray analysis could be applied to these elements, the difference between the atomic masses of the uranium and the resulting lead would include not only the mass of 8 helium nuclei in the free state, but also about 0.05 unit of atomic mass, corresponding to the total emission of energy of about 46 million electron-volts per disintegrating atom of uranium. This difference—about 1 in 4000—should be just detectable by the methods employed by Aston in his study of isotopes." The building up of a helium atom from four hydrogen atoms produces a structure, the helium atom, that has less mass than its constituent parts had. "This indicates a loss of energy of 27 million electron-volts in the process of building a helium nucleus from free protons and electrons. The energy emitted per atom is thus very large, and it has been suggested by

Eddington and others that the formation of helium from hydrogen nuclei may be one of the sources of the energy radiated from the stars." Jeans, on the other hand, suggests that protons and electrons both may turn into radiation and thus account for the age-long shining of the stars. If the energy emitted by simultaneous annihilation of a proton and an electron should be given off in a single quantum its energy would be about 940,000,000 volts. Do the cosmic rays of Kolhoerster and Millikan meet the requirements for such radiation? There is some reason to believe that they do but the evidence is by no means conclusive. "The study of these extraordinarily penetrating radiations is not only of great interest in itself, but also for its promise of throwing new light on fundamental processes in our universe connected with the building up and destruction of atoms." G. F. S.

Isaac Newton. ALBERT EINSTEIN. (From the *Manchester Guardian*, March 19, 1927; reprinted in the Annual Report of the Smithsonian Institution for 1927, published in 1928.) This paper appeared a short time before the two-hundredth anniversary of the death of Sir Isaac Newton, "this shining spirit, who pointed out, as none before or after him did, the path of Western thought and research and practical construction. He was not only an inventor of genius in respect of particular guiding methods; he also showed a unique mastery of the empirical material known in his time, and he was marvellously inventive in special mathematical and physical demonstrations. For all these reasons he deserves our deep veneration. He is, however, a yet more significant figure than his own mastery makes him, since he was placed by fate at a turning point in the world's intellectual development. This is brought home vividly to us when we recall that before Newton there was no comprehensive system of physical causality which could in any way render the deeper characters of the world of concrete experience." The Greek materialists had referred all the phenomena of matter to the motions of atoms governed by law; Descartes had revived this conception but it was largely without foundation before Newton. Knowing Kepler's empirical laws of planetary motion Newton set himself to solve the question "Does there exist a simple rule by which the motion of the heavenly bodies of our planetary system can be completely calculated, if the state of motion of all these bodies at a single moment is known?" The affirmative answer and the solution are found in Newton's laws of motion and of attraction. The impressive success of Newton's method in explaining the complicated motions of the solar system led to its dominating physical research until the close of the nineteenth century. Electrical and

magnetic phenomena were attributed to imponderable substances acting at a distance. Newton tried to explain light effects by inert corpuscles. The kinetic theory of matter employed the laws of motion. Even when Faraday and Maxwell's new conceptions in optics and electro-dynamics came in, Kelvin, Boltzmann and Maxwell tried again and again to clothe the new ideas in the garb of mechanical processes. "Newton himself was better aware of the weak sides of his thought-structure than the succeeding generations of students. This fact has always excited my reverent admiration." Three weak points in Newton's system are indicated by Einstein.

1. His use of the conceptions of absolute space and absolute time.
2. The assumption, in contradiction to our usual experiences, of direct, instantaneously acting forces at a distance.
3. "Newton's theory offered no explanation of the very remarkable fact that the weight and inertia of a body are determined by the same magnitude (the mass). The remarkable nature of this fact struck Newton also."

The first serious blow to Newton's theory came when, in accord with Maxwell's theory it was shown that magnetic and electrical attractions and repulsions are not transmitted instantaneously but travel with a finite speed through space. As a competitor to Newton's point-mass and its movements there arose Faraday's conception of a field as a real physical entity. "We owe to H. Hertz the deliberate liberation of the conception of the field from all the scaffolding of the conceptions of mechanics, and to H. A. Lorentz the liberation of the conception of the field from a material bearer."

The Maxwell-Lorentz theory led to the special theory of relativity. According to this mass is not unchangeable in quantity but is identical with energy, and Newton's laws of motion hold only for small velocities and are comprised in a broader law wherein the velocity of light in a vacuum appears as the highest possible velocity. Then followed the general theory of relativity. "Inertia, gravitation and the metrical behavior of bodies and clocks were reduced to the single quality of a field, and this field in turn was made dependent on the bodies. Space and time were so divested, not of their reality, but of their causal absoluteness, which Newton was compelled to attribute to them in order to be able to give expression to the laws then known."

"The whole development of our ideas concerning natural phenomena, which has been described above, may be conceived as an organic development of Newton's thought,—but while the construction of the theory of fields was still actively in progress, the facts of heat radiation, spectra, radioactivity, and so on, revealed a

limit to the employment of the whole system of thought, which, in spite of gigantic successes in detail, seems to us to-day completely insurmountable. Many physicists maintain, not without weighty arguments, that in face of these facts not only the differential law but the law of causality itself—hitherto the ultimate basic postulate of all natural science—fails." G. F. S.

Cosmic Radiation and Radioactive Disintegration. L. R. MAXWELL and W. F. G. SWANN. Bartol Research Foundation of The Franklin Institute. (*Nature*, Dec. 29, 1928.) Perrin has suggested that the absorption of cosmic radiation is the occasion of the transformations of radioactive substances. To test this hypothesis Dr. Maxwell investigated the activity of polonium at the bottom of the New Jersey Zinc Co.'s mine at Franklin. It was thought that here, 1,150 ft. below the surface of the earth, there might be detected a change in the radioactivity of polonium due to the decrease in the intensity of cosmic radiation caused by its absorption by the superincumbent layer of earth. Within the limits of the experiment, however, polonium displayed the same radioactivity at the surface as at the bottom of the mine. This appears to negative Perrin's theory. Swann, however, basing his argument upon the absorption coefficient of the cosmic rays got by Millikan and Gale and upon Dirac's formula, says: "It is therefore clear that we should only expect a cosmic ray to be absorbed by one of these (polonium) atoms once in about 10^{15} secs., i.e., once in twenty million years. This consideration would appear to render very improbable a direct effect of the cosmic radiation even in the most favorable case." G. F. S.

Bakerian Lecture.—The Aurora and Its Spectrum. J. C. MCLENNAN. (*Proc. Roy. Soc.*, A 785.) Whether in the northern hemisphere, the Aurora Borealis, or in the southern hemisphere, the Aurora Australis, the aurora occurs most frequently in zones that make angles of approximately 20° with the earth's magnetic axis. Magnetic storms generally accompany the aurora and both are attributed to streams of electrons coming from the sun. Such streams, according to Birkeland, would, upon entering the terrestrial magnetic field, follow paths having the shape of the streamers of the aurora. In form and intensity the aurora varies widely. "At times it is seen as a weak, diffuse, formless luminosity; at other times it appears as luminous draperies, bands or arcs, and often only as luminous beams or rays." Sometimes the figures of the aurora are stationary while at other times they move. The brightness may pulsate. Greenish-yellow predominates as the color of

faint, diffuse auroras as well as for those of curtain or arc form with rays and of small elevation. Violet, blue, red and other colors are, however, seen particularly with bright and shifting manifestations. In auroras high above the earth red-violet has been observed and curtains of violet-grey. The spectra of these displays are strong in the short wave-lengths. Størmer since 1907 has made many investigations of the elevation of the aurora. His method depends on photographing the same aurora simultaneously from two stations separated by distances ranging from 4.5 to 258 km. Now only one second is required for the exposure. The stars, photographed at the same time as the aurora, serve as points of reference for the determination of height. Størmer has taken hundreds of photographs of auroras. "His results show that very few displays occur below 80 km., and that above this level the number increases rapidly with the most frequent occurrences, beginning at a height of 106 km. Above this height the number of auroras falls off rapidly. Some, however, have been observed as high as 500 km. and 750 km. One reached even to 1,000 km. The auroras seen at Oslo in general extend higher than those viewed at Bossekop near Finland.

Ångstrom, after whom the unit of wave-length, the Å.U., is named, in 1869 was the first to examine the spectrum of the aurora. He saw a green line and faint lines in the blue. Since that time many have followed him of whom Vegard is the most notable. He has observed 35 or 40 lines or bands. On the other hand it has been known since 1901 that the night sky glows with a faint green light. This holds true for all latitudes, for all parts of the sky, for moonless and cloudless nights and also for moonlit and somewhat cloudy nights. This "non-polar" aurora occurs without dependence on polar auroras or magnetic storms. In the spectrum of the night sky the chief feature is a line in the yellow-green of wave-length 5,577 Å.U., also appearing as a strong line in the auroral spectrum. The polar and the non-polar aurora do not of necessity have the same origin.

Most of the spectrum of the polar aurora is due to the band spectrum of nitrogen. In the auroral spectrum one prominent feature is a group of four bands ranging toward the violet end from 5,227 Å.U. onward. These belong to the first negative band spectrum of gaseous nitrogen. The auroral spectrum contains also three additional but fainter bands of the same system. Further there are about sixteen faint bands in the spectrum of the aurora. These are now identified with members of the second positive band system of nitrogen. There are two bands in the auroral spectrum that are awaiting identification, but one of them seems likely to belong to the band spectrum of nitrogen. In addition the spectrum

has ten wave-lengths ranging from 3,000 to 5,000 Å.U. that are not in the spectrum of nitrogen nor in that of atomic oxygen with perhaps one exception.

The famous green line, 5,577 Å.U., long defied identification. At last in 1925 McLennan and Shrum showed it to be emitted by atomic oxygen. A study was made of the intensity of this line in the spectrum of the night sky. It was found that after sunset the intensity of the green light from the zenith increased until a maximum was attained about one and a half hours after midnight. From this time onwards until sunrise there was a decrease.

G. F. S.

The Velocity of Electrical Waves on Thin Wires of Different Specific Conductivities. L. BERGMANN and G. HOLZLOEHNER. (*Annalen der Physik*, No. 21, 1928.) On the basis of the mathematical investigations of Sommerfeld, Mie and Mercier a formula is derived for the difference between the wave-length of an electrical oscillation in air and the wave-length of the same vibration on a wire. The wave-length in air is the greater by a quantity that is greater as the wave-length increases. For a wire of zero resistance the difference disappears, that is, the velocity along the wire equals the velocity of light. According to the formula the difference in velocities in air and along the wire is inversely proportional to the square root of the specific conductivity and roughly inversely proportional to the diameter. The frequency has the main effect upon this difference.

The measurements were carried out with two frequencies corresponding to wave-lengths of 400 and 172 cm. respectively. Two Lecher systems were employed, the wave-lengths obtained on one system with the different thin wires being compared with the wave-lengths got with a copper wire 1.5 mm. in diameter on the other system with the same oscillation. The wave-length in air is not measured but in its stead is substituted the wave-length on the thick copper wire. The error made thereby lies well within the range of error in the experiment. Measurements were made on wires of copper, aluminium, brass, German silver, manganin and constantin, the diameters varying from .04 to .3 mm. With the higher frequency (wave-length of 400 cm.) the difference between the wave-length in air and the wave-length on the wire is in general rather more than three times the difference for the lower frequency (wave-length of 172 cm.). This holds true for all materials investigated and for all diameters. For example with copper .04 mm. in diameter the difference for high frequency is 4.50 cm. and for low frequency 1.33 cm. The thicker the wire the smaller the

difference as should be the case according to the theoretical formula. For copper wires of diameters .04, .06, .10, .15, .20 and .25 mm. the differences for the higher frequencies were 4.50, 3.20, 1.90, 1.50, 1.05 and .90 cm. respectively.

Constantin has a much lower specific conductivity than copper. Hence it is not surprising to note for the same frequency and the same diameter that constantin shows a difference of velocity of 6.50 and copper only 1.05 cm. When the calculated differences are compared with those observed it appears that the agreement is quite good, especially for wires of larger diameters and high specific conductivity.

With the higher frequency, 7.5×10^7 cycles per sec. (wave-length of 400 cm.) the smallest difference between the velocity in air and the velocity on the wire was observed to be .9 cm. This means that the electric wave in air outruns the wave along the wire at the rate of 6,750 km. per sec. G. F. S.

Absolute X-Ray Wave-Length Measurements. A. P. R. WADLUND. (*Phys. Rev.*, Dec., 1928.) Hitherto most of the measurements of the wave-length of X-rays have been made by means of reflection from a crystal. Uncertainty in the exact value of the crystal grating space introduced a corresponding uncertainty into the calculated wave-length. Mr. Wadlund, working in the Ryerson Physical Laboratory, has sought with success to obtain accurate values of the wave-lengths by using a diffraction grating ruled on speculum metal. The rulings were 2 cm. long and the group covered a width of 5 mm. The grating space was .02 mm., i.e., 50 lines to the mm. The grating was ruled on one of Michelson's engines and was especially free from ghosts.

For the K_{α_1} lines of copper, iron and molybdenum the wave-lengths are calculated to be in Ångstrom units 1.5373, 1.937 and .708 respectively. The crystal grating space of calcite is computed to be 3.029 Å. This agrees well with the value of 3.033 Å. derived by Baecklin from measurements made on the K_α line of aluminium.

From the wave-lengths determined in this paper Avogadro's Number and the electrostatic charge on an electron are calculated to be 6.061×10^{22} and 4.774×10^{-10} e.s.u. respectively. Millikan's values from his oil-drop measurements are just the same, the only difference being that his probable errors are somewhat smaller.

G. F. S.

The Influence of a High Potential Direct Current on the Conductivity of an Electrolyte. J. A. H. LEECH-PORTER and T. ALTY. (*Phil. Mag.*, Jan., 1929.) "A cylindrical cell 7 cm. long and 2.5 cm.

in diameter and having platinum end-pieces was filled with distilled water and the resistance between the end-pieces was measured. A potential of 240 volts was then applied between the platinum plates for some minutes, after which the resistance was again measured. Usually the application of the potential increased the conductivity by about 100 per cent. On stirring the water the original resistance was restored." The resistance was found by the use of an alternating current. Another form of the experiment was this. The cell was filled with water and 40 volts were applied for 10 minutes. Then the resistance was measured. A potential of 80 volts was then applied and the resistance measured after the lapse of 10 minutes. This was continued up to 600 volts. The cell was refilled and the series repeated with voltages decreasing from 600 to 40. With both increasing and decreasing voltages the change of resistance was greatest at 80 volts. The number of ohms of change in the resistance was likewise independent of the ascending or descending sequence.

Since the alternating voltage for measurement of resistance and the direct voltage were both applied at the electrodes the effect observed might be attributed to some change in the electrodes. To clear this up a modification was introduced. Two large electrodes in dilute HCl were used for the direct voltage only, and the resistance was measured by exploring electrodes placed in the liquid between the main electrodes. Thus any change of the latter would be without effect on the resistance between the auxiliary electrodes. After the D.C. current had flowed for a while the resistance midway between the large electrodes was always greater than before the passage of the current. Near either electrode, however, the resistance was much reduced. The normal resistance was restored by stirring.

Again, two pairs of exploring electrodes were kept in the liquid, the line joining the two members of each pair being parallel to the faces of the large electrodes. One pair was as far from the positive electrode as the other pair was from the negative one. Minute by minute the resistance of the liquid between the electrodes of each pair was measured, while the D.C. current was flowing. "The resistance across one pair of electrodes increased while that across the other decreased. When the current was reversed, the resistances (at the two pairs of exploring electrodes) were interchanged. Also, on reversal, it will be noted that the conductivity at both pairs of electrodes first rises to a maximum and then falls to an equilibrium value. If the current be again reversed, this same effect is repeated." The following seems to be the explanation. When the D.C. voltage is applied ions are swept out of the liquid

and collect at the electrodes. The liquid midway between the electrodes has a high resistance because it is poor in ions. It is the resistance of the pair of electrodes near to the positive electrode that diminishes while the resistance near to the negative plate increases. This may indicate that the cathode holds its ions closer than does the anode. It may be that the difference depends on different rates of diffusion for the positive and the negative ions since at an electrode the ions will be in a state of temporary equilibrium resulting from the interaction of the current effect and of diffusion. A study of the change of resistance at the two pairs of auxiliary electrodes taking place when the D.C. voltage is reversed indicates that the anions and the cations move across to the opposite electrode in a group and not in a straggling procession. Observations of the negative Cl ion show that it moves with a velocity of about 74×10^{-5} cm./sec. when the difference of potential in the liquid is one volt per cm. G. F. S.

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